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AMERICAN JOURNAL OF SCIENCE

JULY 1938

A SHELL-BORING GASTROPOD IN A DALMANELLA BED OF UPPER CINCINNATIAN AGE.

WALTER H. BUCHER.

ABSTRACT.

First a brief summary is given of present-day knowledge concerning the shell-boring habits of modern gastropods. Then a new, unusually instructive case of shell-boring is described from Upper Cincinnatian (Richmond) beds. Reasons are given for suspecting the boring to have been done by a species of the Genus *Holopea.*

In 1853, Troschel holding a large captured *Dolium galea* in his hand, noted that the liquid which the snail squirted from its long proboscis caused the marble slab of the floor to effervesce. He found that the liquid contained three to four per cent of sulphuric acid, secreted by two large glands which discharge into the buccal cavity.[1] This and other acids have since been found in a number of other marine prosobranchs (e.g., *Tritonium, Mitra, Conus,* etc.). These snails are rapacious carnivores that get hold of their prey by means of the large teeth on the radula within the extensible proboscis. A large *Tritonium nodiferum,* for instance, has been seen to swallow a starfish (*Asterias*) with a disc diameter of 26 cm. and weighing 134 g. "In four hours the starfish had disappeared within the snail with the exception of the tip of one arm, which stuck from the snail's pharynx even after eight hours, but had vanished the next morning."[2] In view of such diet, the physiological significance of the acid secretion is no mystery.

Early the suspicion arose that the same or a more specific

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[1] Léon Fredericq: "Handbuch der vergleichenden Physiologie," 2 Bd., 2. Hälfte, pp. 65-75, Jena 1924.

[2] Ibid., 2. Bd., 1. Hälfte, pp. 929-935, Jena 1911.

AM. JOUR. SC.—FIFTH SERIES—VOL. XXXVI, No. 211, JULY, 1938.

secretion of acid entered into the process by which some prosobranchiates bore into shells of living animals to feed on their bodies. In the case of *Natica,* a conspicuous disc-shaped body on the underside of the proboscis, directly below the mouth, was suspected to have the function of an acid-producing gland and was so designated by Schiemenz.[3] Yet, while such a function seemed indicated by a number of facts, the actual presence of an acid in or on the "gland" was not demonstrated satisfactorily until very recently.[4]

But other notorious shell-borers such as our own oyster-drill *Urosalpinx cinerea* and its British competitor *Purpura* (*Nucella*) *lapillus* (both of the family *Muricidae*) lack such a visible special organ. Zoölogists are still inclined to believe they actually drill mechanically by means of their radulas. But the reasons given are not convincing. In view of Ankel's experience with *Natica,* the fact that no free acid has been demonstrated[5] in either the buccal cavity or the oesophagus of the oyster drills cannot be considered proof of its absence. More important are the signs of wear seen on the radulas of these forms. In a specimen of *Purpura lapillus,* Sollas found every one of the teeth in the mouth-cavity with cusps broken off.[6] According to Ankel, considerable wear on the first two or more dozens of radula teeth has been observed in both *Urosalpinx* and *Nucella.*[7] While this shows that the radula is used by these forms for scraping, it does not prove that the mechanical action is the sole or even the chief factor in the process of shell boring.

To the writer the remarkable circularity of all drill holes made by snails and the fact that they invariably penetrate the shell at right angles to the surface appear inexplicable as the result of mechanical action alone. The radula is a ribbon, narrower than the proboscis and bearing teeth only on one side. Motion is possible only from one side to the other. The snails attack their prey from all sorts of angles. The achievement of perfect circularity and perpendicularity with such a tool would seem almost a miracle. Chemical action, on the other hand, proceeding along the appressed tip of the terete proboscis, would automatically produce a circular hole and would work downward at right angles to the surface. It would also suggest an explanation for the presence, side by side, of drill holes with beveled edges and such without. The beveling, which always converges toward the interior of the shell, seems to indicate that the solvent action continued along the outer surface while the center is being lowered into the shell. In the case of a slender proboscis, with the tip only appressed against the shell, the solvent action of the weak acid aided by the scraping of the radula would sink a hole with nearly vertical walls through the shell.[8] Since the teeth of the oyster drills consist of chitin more or less reinforced along the surface with calcium and iron phosphate,[9] it is to be expected from this auxiliary activity that they should show more or less damage. A thick, fleshy proboscis, on the other hand, would tend to press the sides of the proboscis against the shell over an area wider than the tip and would thereby tend to cause solution to continue along the surface even while the tip is penetrating below the surface. The drill holes which *Natica* produces by means of a gland that is situated on the side of the proboscis, i.e., entirely without the aid of the radula, show exceptionally wide beveling, as is to be expected according to the suggestion here made.

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[3] Schiemenz, K.: "Wie bohrt *Natica* die Muscheln an?" Mitt. Zool. Station, Neapel, Vol. 10, 1891.

[4] Ankel, W. E.: "Wie bohrt *Natica*?" Biol. Zentralblatt, Bd. 57, H. 1-2, 1937. The author produced solution effects on glossy shell fragments by pressing against them such glands freshly cut from the living animal.

[5] E.g., Pelseneer, P.: "Comment mangent divers gastropodes aquatiques?" Ann. Soc. Royal Zool. de Belge, Vol. 55, 1925.

[6] Sollas, I. B. J.: "The Molluscan radula: its chemical composition, and some points in its development." Quarterly Journal of Microscopical Science, N. S., Vol. 51, p. 128. 1907.

[7] Ankel, W. E.: "Prosobranchia," Part IXb of "Die Tierwelt der Nord- und Ostsee." Akad. Verlagsgesellschaft, Leipzig, 1936.

The writer wishes to thank Dr. W. Häntzschel for calling his attention to Ankel's valuable papers and Professor Ankel for reference to Sollas' paper.

It seems probable, therefore, that when one traces back in geologic time this curious habit of some snails of boring through the shells of lime-secreting organisms,[10] one is actually tracing a peculiar physiological property, that of secreting free acid. As far as the writer knows, the earliest cases of round bore holes made by carnivorous snails have been found in the

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[8] The rate of drilling is quite slow. The oyster drill, *Urosalpinx cinerea,* e.g., which is common from Massachusetts to the East Coast of Florida, drills only 0.4 mm. in 24 hours.

Federighi, Henry: "Studies on the oyster drill," U. S. Dept. of Commerce, Bureau of Fisheries, Vol. 47, Bull. 4, p. 110. 1931.

[9] It seems that silica (opal) occurs only in the *Docoglossa,* reinforcing the chitin of the radula teeth. See I. B. J. Sollas, loc. cit.

[10] Our modern borers attack not only pelecypods, but other gastropods amphineurs, and cirrhipeds (*Balanus*) as well.

Upper Cincinnatian. The Fentons[11] have figured three specimens from the Waynesville formation (Lower Richmond) which look typical. One circumstance, however, caused the writer to doubt the nature of these specimens as well as of two

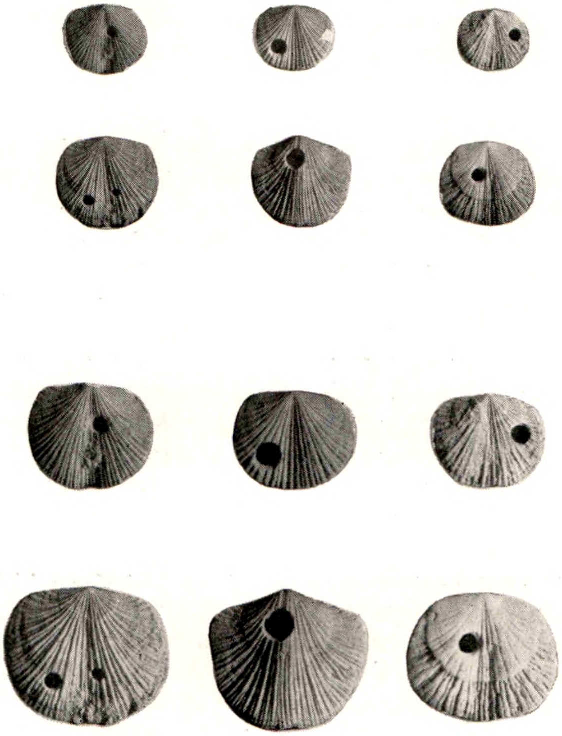

Fig. 1. Six valves of brachiopod shells [*Dalmanella meeki* (Miller)] with holes made by a shell-boring gastropod. The small brachiopod shells at the top of the figure are (a) natural size. The brachiopod shells at the bottom of the figure are (b) enlarged.

From the Waynesville formation of the Richmond Group of the Upper Ordovician, near Oxford, Ohio.

which are in the Geology Department at Cincinnati: They seemed to represent extremely rare finds. These five specimens represent each a unique find of a bore hole for each of the species mentioned (2 species of *Platystrophia*, one each of *Rafinesquina, Dalmanella, Sowerbyella*). These are all species

[11] Fenton, C. L., and Fenton, M. A.: "Some snail borings of Paleozoic age," American Midland Naturalist, Vol. 12, pp. 522-528. 1931.

of which hundreds, if not thousands of specimens were seen annually by the writer and his students in the field, in over twenty years, without a drilled one having been found. Years ago the writer looked through the very large number of Cincinnatian brachiopods in the collections of his department in search of evidence of snail bore holes. Recently one of his graduate students, Miss Lucile Miller, did the same for our (much smaller) collection of Cincinnatian pelecypod shells.[12] Not one shell was found with an undoubted borehole. Such scarcity is entirely contrary to the well-known habits of our modern shell-boring gastropods. A single oyster drill (*Urosalpinx cinerea*) is capable of killing from 30 to 200 oysters in one season, depending on the size of the oysters.[13] Careful studies[14] have shown that in the vicinity of Hampton Roads, Va., about two per cent of the oysters are dead through the activity of *Urosalpinx cinerea,* while under the artificially crowded conditions of planted bottoms the percentage rises to approximately ten per cent.

That the shell-borers were no less hungry in Tertiary times is shown by the abundance of shells with bore-holes.[15] So long as bore holes in Early Paleozoic shells were known to be so rare as to be curios, doubt concerning their origin seemed justified.

At last, however, the writer has come upon a Brachiopod layer in which bore holes occur in relative numbers quite comparable with those of modern days. The specimens, of which six are reproduced in the accompanying figure,[16] were obtained in a small tributary (Bull Run) on the west side of Fourmile Creek which runs approximately in an east-west direction just south of Oxford, Ohio. Here, *Dalmanella meeki* (Miller) forms regular banks in the Waynesville formation of the Richmond series. In a thin shale layer from which the shells could be withdrawn freely, about two dozen shells were obtained in a short time, each perforated by circular holes unmistakably like those produced by modern shell-borers. The holes lie anywhere on either valve, a condition to be expected in the case of shells that lay flat on the bottom with valves differing but little in convexity. Most of the holes are not beveled, but a few show moderate beveling, as for instance one of those here figured. Even the comparatively rare case of two holes in one shell was found (see illustration).

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[12] Most of these are inner molds and would, therefore, show the bore hole as a round cylinder set on top of the mold.

[13] Federighi, Henry: "Control of the common oyster drill," U. S. Dept. of Commerce, Bureau of Fisheries, Economic circular No. 70, March, 1930. (Oysters to the value of several million dollars are destroyed annually by *Urosalpinx* in the United States alone.)

[14] Federighi, Henry: "Studies on the oyster drill," U. S. Dept. of Commerce, Bureau of Fisheries, Vol. 47, Bull. 4, 1931.

[15] Klähn, Hans: "Der Bohrakt fossiler bohrender Schnecken und das Vernichtungsmass durch räuberische Gastropoden des Sternberger Oligocaen." Sitz. Ber. u. Abh., Naturf. Ges. Rostock, 3, Folge, Bd. 3, pp. 89-103. 1932.
Ichiro Hayasaka, "Fossil occurrence of Pelecypod shells bored by certain gastropods." Mem. Faculty of Science and Agriculture, Taihoku Imperial University, Vol. 6, No. 4, 1933. For an excellent general discussion see O. Abel, "Vorzeitliche Lebensspuren," Jena pp. 373-378. 1935. Here also references to Permian (Yakovlev) and Devonian (J. M. Clarke) cases.

[16] The writer wishes to thank Miss Lucile Miller for photographing the specimens for him.

A special effort was made to find gastropods in the same bed, but in vain. If the guilty form had a preservable shell—which is probable though not certain—it should be among those recorded from the Waynesville formation. Three clues present themselves. First, none of the species commonly found in brachiopod layers can be held responsible, since otherwise bore-holes should be of common occurrence. This excludes at once all the common species of *Cyclonema, Lophospira,* etc. Second, it is not to be expected that the habit of boring appeared in groups with shells of patelloid or bellerophontoid type, such as for instance *Archinacella* or *Salpingostoma.* Third, the size of the boreholes points to a shell decidedly larger than the common oyster drill. The shell of *Urosalpinx* is typically 28 mm. long and 16 mm. wide (1⅛″ and ⅝″). The holes it drills measure[17] about 0.75 to 1.5 mm. in diameter. This is decidedly less than the dimensions of holes in the *Dalmanella* shells here described, the diameter of which ranges from 1.0 to 2.5 mm. It seems reasonable to assume that the corresponding gastropod was proportionately larger.

The faunas of the horizons of the Cincinnatian formations in the vicinity of Oxford have been studied for many years by Professor W. H. Shideler and his students. When the writer gave the essence of this paper before the Ohio Academy of Science in the spring of 1936, Professor Shideler stated that the only gastropod found so far in the horizon from which the bored shells were collected, is a species of *Lophospira, Lophospira perlamellosa* Ulrich.[18] This species is sufficiently different from the common forms of *Lophospira* to fulfill the first of the three conditions listed above. Ulrich's type is, however, much smaller than *Urosalpinx* (13 mm. in height). It should be remembered, however, that other species of *Lophospira* show great variation in size. The closely allied Richmond species, *L. ampla* Ulrich, for instance, varies between 22 and 50 mm. in height.[19] It is not at all impossible that the type specimen lies near the lower limit of size, since no specimens were collected from the particular bed in which the bored shells were found.

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[17] For good illustrations see Churchill, E. P.: "The oyster and the oyster industry of the Atlantic and Gulf Coasts"; App. VIII to Rept. of U. S. Comm. of Fisheries for 1919, pp. 1-51, esp. pl. 8, opp. p. 38. 1920.

[18] Ulrich, E. O.: "The Geology of Minnesota," Final Report, Vol. III, pt. II, p. 985; p. 73, Figs. 55 and 56, 1897.

It seems possible, therefore, though by no means certain, that this species of *Lophospira* acquired the habit of boring into shells. Whether a single individual now and then hit accidently on this method of feeding, or whether boring had become already an essential habit, can be decided only through a systematic search for evidences of boring in Richmond beds.

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[19] Ulrich, E. O.: loc. cit. p. 981; pl. 73, Figs. 52-54, 1897.

UNIVERSITY OF CINCINNATI,
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ANALCITE-BEARING INTRUSIVES FROM SOUTH PARK, COLORADO.

RICHARD H. JAHNS.

ABSTRACT.

Sills and dikes of analcite diabase and analcite syenite occur as low ridges on the flat floor of South Park, Colorado. The intrusions appear in Cretaceous shaly sandstone, and are probably Laramide in age. Certain features suggest a composite nature for the larger bodies, with the syenitic rock having been injected into pre-existing, but not yet completely solid diabase. Both types contain analcite, some of which is pyrogenetic. At least three mineral reaction series are well shown; all point to crystallization of an alkaline and water-rich magma at low temperatures, with development of a highly sodic residual liquid. The lack of any apparent break between the pyrogenetic and hydrothermal stages suggests for this rock a genetic nature tending in its end stages toward that of veins.

For many years petrographers have shown much interest in the rather rare and unusual group of analcite-bearing minor intrusives. This seems due not only to the difficulties in their classification, but to the striking structural and petrologic similarities in widely separate occurrences of these rocks, as well as to the perplexing problem of their genesis. Excellent exposures of analcite diabase and analcite syenite were encountered in South Park, Colorado, and it is to their description and a suggested explanation of their origin that this paper is devoted.

The work was done in 1935-36 under the auspices of Northwestern University and the Geological Society of America. Grateful acknowledgments are made to Charles F. Henderson for his efficient field assistance, to Dr. A. L. Howland of Northwestern University for his invaluable suggestions in field and laboratory, and to Dr. Ian Campbell of the California Institute of Technology and Dr. James Gilluly of the U. S. Geological Survey for critical reading of the manuscript.

FEATURES OF OCCURRENCE.

South Park is a large, relatively flat-floored intermontane basin near the geographic center of Colorado. The intrusions in question appear as low ridges on the Park floor three miles north of Hartsel and six miles southeast of Garo. A small dike, a larger sill, and several minor sill-like masses are localized in sections 20 and 21, Township 11 S., Range 75 W., where they intrude the Upper Cretaceous Fox Hills sandstone. The encountering of eleven other bodies of similar rock during drilling of an oil well into the Pierre shale in section 16 suggests a system of sills at depth. So far the writer knows, there are no other igneous bodies of this nature in South Park, and very few have been reported from the Front Range region in general.

The typical discordant type of structure is shown on a knob in section 20, where the intrusion appears on the western flank of an anticline in the Cretaceous beds (see Fig. 1). Generally speaking, it is a north-northwest trending dike which dips eastward 45°-55°. From narrow wedges at the two extremities, it swells and pinches, reaching a maximum thickness of approximately 150 feet near its northern end. Its length along the strike is nearly a quarter-mile.

The adjacent sandstone beds are markedly disturbed; large-scale dragging by the intrusion has upwarped the strata on the east and has overturned them on the west in a manner unaccountable on the basis of purely tectonic causes. Though contact metamorphism has rendered them brittle, they show surprisingly little fracturing or brecciation.

The dike itself is resistant, appearing as a dark zone along the crest of the ridge. On the southern end, the rock is coarse grained and melanocratic; it weathers concentrically into rounded, onion-like boulders. Although the extreme edges of the dike are not exposed, the presence of a chilled margin is shown by abundant float on the hill slopes. A vuggy, lighter colored phase appears to the north, but its relations to the basic rock are obscured by a surface cover. Both types are irregularly jointed.

The largest member of the series is the sill-like mass which crops out on Oil Well Ridge (Fig. 1). It is concordant in most places, dipping westward 30°; its southern extensions, however, strike across the bedding of the Fox Hills sandstone, which shows evidence of severe disturbance. A small patch of Oligocene trachyte caps the intrusive near the southern edge of the ridge, and is presumably an erosional remnant of a once-extensive flow.

The sill itself is composite, and may be divided into three units: (1) a chilled border zone, (2) a coarse-grained, melancratic facies, which is the dominant rock type, (3) a more silicic type. The border zone is found at all exposed

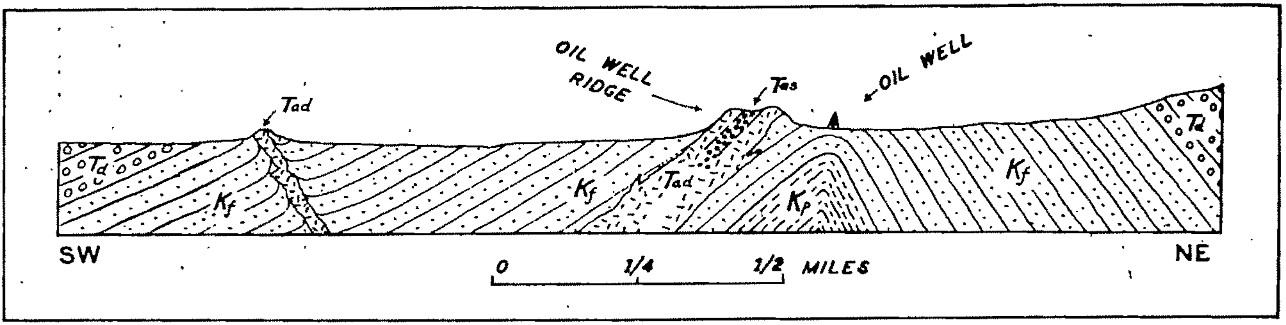

Fig. 1. Generalized section across the area of analcite-bearing intrusives, South Park, Colorado.

K_p ....Pierre shale.
K_f ....Fox Hills sandstone.
T_d ....Denver formation.
T_{ad} ....Analcite diabase.
T_{as} ....Analcite syenite.

Vertical scale = horizontal scale; topography exaggerated approximately x 5. (The oil well is actually located a quarter-mile northwest of the line of section.)

contacts with the adjacent sediments, and varies in thickness from a half-inch to two feet. It passes transitionally into the mafic rock, which itself gives way very gradually to the more felsic phase near the center of the sill. Relations between this core and the surrounding mantle of mafic rock are masked by surficial debris, which tends to collect in the elongated topographic depression developed on the less resistant silicic type. The lack of resistance to erosion seems due to its high analcite content.

Small aplitic stringers near the south end of the intrusion, however, can be traced through the mafic rock into the felsic core, from which they were probably squeezed out during the final stages of magmatic activity. They vary from a quarter-inch to several inches in thickness, and have irregular contacts which are in places sharp, in other places gradational. Their regular spacing and sub-parallelism suggest injection along zones of weakness in the partially consolidated mafic rock; that they are not the results of gravitative differentiation in place is seen from their remarkable continuity, their occurrence near the base of the sill as well as near the top, and the intrusive features of their contacts with the surrounding rock.

The sequence of intrusion, on the basis of field relations, seems to be (1) injection of a sill-like mass of rather basic material, which developed a chilled border zone against the country rock, (2) either injection of a more silicic differentiate into the "mushy" basic material near the center of the sill or a concentration of the silicic core by differentiation in place. In either case, there followed a squeezing out from this core of aplitic stringers essentially parallel to the elongation of the main intrusive mass.

On a small offshoot of the large sill there is an unusually fine development of spheroidal weathering, but this is not common elsewhere. Much of the main mass shows sheet jointing rudely parallel to the bedding of the adjacent sandstone; it is along these joints that the aplitic stringers were injected.

The eleven small bodies encountered in the oil well vary in thickness from a few inches to about fifty feet. That they are essentially concordant with the bedding of the surrounding Pierre shales is suggested by their dips (although the drill cores were not oriented, they showed absolute dips of the igneous bodies nearly equal to those of the strata) and by the fact that in most cases gas was encountered directly beneath them.

All the above mentioned intrusions may be genetically related with two plug-like masses of quartz monzonite which lie only a mile to the west. In the general vicinity no bodies other than the quartz monzonite are of the same post-Cretaceous age. Preliminary studies have shown the latter to be late in the Laramide intrusive series of the southern Rockies, and therefore early Eocene. A similar specific age assignment seems not unreasonable for the sills and dikes in question.

ANALCITE DIABASE.

General description

The chilled phase of the analcite diabase is characteristically dense and fine grained, with a sub-conchoidal fracture. It is very dark gray, scarcely distinguishable from the metamorphosed shaly horizons of the Fox Hills formation, into which it locally grades with no perceptible break. Toward the central part of the body it passes with gradual increase of grain size into diabase, the dominant component of the intrusive masses.

This mafic rock type, which is fairly uniform in all its exposures, is dense, coarse grained, and dark gray. It is much like a typical minette, for biotite flakes, commonly as large as three millimeters in diameter, cover most of the areas of its rough, irregular fracture faces. These flakes are locally fresh and brilliant black, elsewhere a dull, rusty-bronze.

Close examination reveals much light gray to olive green interstitial material, chiefly calcic plagioclase and a pyribole. Sufficient magnetite is present to interfere with normal operations of a compass. Calcite is disseminated through the rock, but can be recognized only by testing with acid.

Microscopic features.

Under the microscope the chilled phase (as distinguished from the diabase) shows a fine-grained, inequigranular, idiomorphic texture, with profuse development of minute feldspar laths. Interstitial to the feldspars are smaller euhedra of augite, sphene, and biotite. Their approximate relative abundance is shown in Table 1.

TABLE 1.

Mineral composition of chilled phases of diabasic intrusions.

Feldspar	52
Analcite (?)	4
Augite	17
Biotite	11
Olivine	4
Apatite	2
Sphene	1
Magnetite	4*
Ilmenite	1*
Calcite	1
Finely divided iron oxide	3

* Percentage obtained from magnetic separation in heavy mineral investigations.

The feldspars are perfectly euhedral and are arranged in separate, sheaf-like groups. Both orthoclase and plagioclase occur; the latter is commonly twinned according to the Carlsbad and albite laws. Biotite occurs as reticulated plates, is green (rare) and brown in color, and is pleochroic in shades of yellow and brown. Stubby augite euhedra and highly corroded olivine masses are distinguished with difficulty through a thin film of finely divided iron oxides.

Most of the mineral grains are too small to permit detailed investigation of their optical properties. Magnetite and apatite alone are exceptions; their relatively large size suggests early crystallization.

The microscope shows the typical diabase to consist of labradorite, orthoclase, analcite, augite, olivine, biotite, hornblende, apatite, magnetite, ilmenite, epidote, chlorite, calcite, and zeolites. Their relative quantities, as ascertained by Rosiwal measurements on typical specimens, appear in Table 2. The texture is coarse grained, idiomorphic, and seriate. Apatite, biotite, and augite form the larger units, though only apatite occurs in strikingly large crystals.

The labradorite in this rock has the composition $Ab_{46}An_{54}$. Complex twinning is characteristic; albite, Carlsbad, pericline, and (rarely) Manebach types are all present. The albite twinning is commonly, though not always, thin and fine, which suggests the presence in solid solution of small amounts of the potash feldspar molecule.[1]

Extinction angles of the orthoclase are unusually high (up to 18°, $X \wedge 001$) and indicate a high soda content. It is optically negative, and may be anorthoclase in some cases; its optic angle, however, is too high (75°-80°). Gilluly[2] notes a similar soda-rich orthoclase in a sill near Emery, Utah, and concludes that it is intermediate in composition between $KAlSi_3O_8$ and $NaAlSi_3O_8$. Other characteristics of the feldspar are its extreme elongation parallel to the *a*-axis and its tendency to develop Carlsbad twins.

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[1] Tyrrell, G. W.: On some dolerite-sills containing analcite-syenite in central Ayreshire, Quart. Jour. Geol. Soc., Vol. 84, p. 548, 1928.

The analcite is recognized by its isotropism and very low index of refraction, which is 1.486 ± .003. It is clear, rarely shows its cubic cleavage, and is free from inclusions. Anomalous birefringence is seen in some grains, but is not common. Thomsonite or some closely related zeolite is sparingly distributed throughout the rock. Its indices are higher than that of the analcite, it shows nearly parallel extinction, and is biaxial with an optic angle of about 55°.

Augite is the predominant mafic mineral, and is present as distinct, grass-green euhedra. It is optically positive, with an extinction angle of 42°, $Z \wedge c$. In certain grains, a reddish brown color suggests a titaniferous variety; such crystals are weakly pleochroic, X = greenish yellow, Y = reddish, Z = greenish yellow, and are commonly associated with masses of ilmenite.

Biotite, occurring as angular euhedra (not uncommonly the pseudo-hexagonal basal plates), is strongly pleochroic, X = straw yellow, Y = Z = dark red-brown.

Olivine is present as highly fractured crystals, which are in advanced stages of alteration to calcite, epidote, and a reddish serpentine. It is optically positive and/or negative, with a very large optic angle and weak dispersion, $r < v$.

The irregular, pale green crystals of hornblende are non- or only faintly pleochroic and optically negative. The extinction angle, $Z \wedge c$, is 23°.

Mineral paragenesis is very clearly shown. Magnetite and apatite euhedra, the latter attaining lengths of 5 mm., are the early products of crystallization, and are included poikilitically in biotite, much of which is only slightly later. Olivine, another early mineral, is extensively corroded and resorbed through deuteric action; its crystals are surrounded by masses of ilmenite, magnetite, and calcite. Pseudomorphs of calcite after olivine are not uncommon. Augite and labradorite are contemporaneous with the biotite, but orthoclase is definitely later.

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[2] Gilluly, James: Analcite diabase and related alkaline syenite from Utah, This Journal, Vol. 14, p. 202, 1927.

Certain biotite crystals have ragged edges characteristic of resorption, but this feature is not everywhere present. That this mineral had a wide time range of crystallization is suggested by its idiomorphic intergrowths with analcite (Fig. 2).

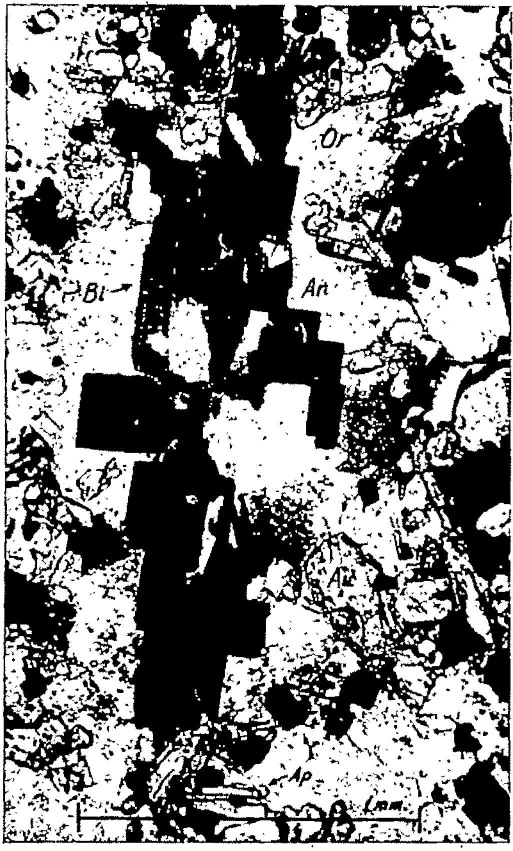

Fig. 2. Idiomorphic intergrowth of analcite (An, white) and biotite (Bi, dark), analcite diabase from Oil Well Ridge. Other minerals are orthoclase (Or), augite (Au), and apatite (Ap).

The analcite is late, but in part pyrogenetic, as shown by its idiomorphic intergrowths with primary magmatic minerals. Elsewhere it replaces feldspar (both orthoclase and plagioclase) along cleavage and fracture planes, and is not rare as individual fillings of fissures developed along cleavages in biotite. Where observed, the thomsonite (?) is later than the analcite, but does not replace it. Late calcite (as distinguished from that associated with the olivine) clearly invades the zeolites.

Nomenclature

The name analcite basalt was first applied by Lindgren[3] to rocks of this type from the Highwood Mountains, Montana. Cross[4] and Ross[5] followed his generally accepted example, although Pirrson[6] advocated the use of Rosenbusch's term, monchiquite. More recently Gilluly[7] has described a similar rock from Utah, the mode of occurrence and petrologic characteristics of which resemble very closely those of the South Park sills and dikes. His designation of analcite diabase seems more appropriate than analcite basalt in this instance, in view of the intrusive nature of the rocks, as well as their coarse texture and lack of a glassy base.

Occurrences of other closely allied rock types have been reported from the British Isles by Tyrrell,[8] Smith,[9] and Tomkeieff[10]; from New Mexico by Ogilvie[11]; from Virginia by Shannon[12]; and from Montana and Colorado by Ross[13] and Knopf.[14] These are but a few examples taken from the surprisingly long list of known analcite-bearing diabasic intrusives as recorded in the literature.

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[3] Lindgren, Waldemar: Eruptive rocks from Montana, Proc. Cal. Acad. Sci., Ser. 2, Vol. 3, pp. 39-57, 1890.

[4] Cross, Whitman: An analcite-basalt from Colorado, Jour. Geol., Vol. 5, pp. 692-693, 1897.

[5] Ross, C. S.: A Colorado lamprophyre of the verite type, This Journal, Vol. 12, pp. 227-229, 1926.

[6] Pirrson, L. V.: On the monchiquites or analcite group of igneous rocks, Jour. Geol., Vol. 4, pp. 679-690, 1896.

[7] Gilluly, James: Analcite diabase and related alkaline syenite from Utah, This Journal, Vol. 14, pp. 199-211, 1927.

[8] Tyrrell, G. W.: The picrite-teschenite sill of Lugar, Ayreshire, Quart. Jour. Geol. Soc., Vol. 72, pp. 84-131, 1916.

————: On some dolerite sills containing analcite-syenite in central Ayreshire, Quart. Jour. Geol. Soc., Vol. 84, pp. 540-569, 1928.

[9] Smith, H. G.: New lamprophyres and monchiquites from Jersey, Quart. Jour. Geol. Soc., Vol. 92, pp. 365-383, 1936.

[10] Tomkeieff, S. I.: The volcanic complex of Calton Hill, Quart. Jour. Geol. Soc., Vol. 84, pp. 712-718, 1928.

[11] Ogilvie, I. H.: An analcite-bearing camptonite from New Mexico, Jour. Geol., Vol. 10, pp. 500-507, 1902.

[12] Shannon, E. V.: The mineralogy and petrology of intrusive Triassic diabase at Goose Creek, Loudoun County, Virginia, Proc. U. S. Natl. Mus., Vol. 66, pp. 22-41, 1924.

[13] Ross, C. S.: Nephelite-hauynite-alnoite from Winnett, Montana, This Journal, Vol. 11, pp. 218-227, 1926.

————: A Colorado lamprophyre of the verite type, This Journal, Vol. 12, pp. 217-229, 1926.

[14] Knopf, Adolph: Igneous geology of the Spanish Peaks region, Colorado, Bull. Geol. Soc. America, Vol. 47, pp. 1727-1784, 1936.

ANALCITE SYENITE.

General description

The vuggy nature of the typical analcite syenite gives it a distinctive appearance, the white cavity-linings standing out distinctly against a mottled, greenish gray background. Nearly equidimensional biotite flakes, commonly as large as six millimeters, long laths of white feldspar, and pod-like masses of pyribole make up the rather even-grained groundmass. Though lustrous, the biotite is mottled and rusty in appearance and shows much evidence of corrosion, especially by zeolitic material.

Analcite lines the cavities, which vary in diameter from a half-millimeter to one centimeter. The mineral is massive, shows rare traces of cubic cleavage, and commonly encloses large flakes of biotite. Not only is it a simple cavity filling, but it appears to have grown into the rock at the expense of other constituents, for its contacts with the groundmass are generally gradational and very irregular. In rare instances zeolites are megascopically identifiable in the cavities; radiating fibers of thomsonite, long, prismatic crystals of natrolite, and sheaf-like masses of stilbite are the species recognized.

An unusual feature is a vein-like mass approximately five millimeters in thickness, from which most material has been leached. The residuum is a reticulated, felt-like mass of tabular orthoclase crystals, some of which are over a centimeter in length.

A slightly aberrant type is the analcite syenite which forms the core of the sill on Oil Well Ridge. It is characterized by its long, bladed biotite crystals, which give it a reticulated appearance, rather than by an extensive system of vugs. The black blades vary from one to twelve millimeters in length, and are set with no observable orientation in a fine-grained, equigranular groundmass composed of analcite and tabular feldspar crystals. The prevailing color is pinkish gray, though in some facies it is a dead white.

Microscopic features

Mineral assemblages of the analcite syenite are qualitatively but not quantitatively similar to those of the chilled phase and the analcite diabase, as seen from a comparison in Table 2. The typical texture is coarse grained and idiomorphic, with local development of vuggy, reticulated, seriate, and porphyritic types.

Calcic plagioclase is absent; the dominant feldspar is sodic orthoclase, with smaller amounts of difficultly distinguishable anorthoclase. These two minerals are grouped together in Table 2. Albite is spotty in its occurrence. Multiple twinning is irregularly developed and in no case are the individual laminae sharply defined. Maximum extinction, measured on twinning, is 17° in the face normal to (010).

TABLE 2.

Mineral compositions of principal phases of analcite-bearing intrusives.

	1	2	3
Labradorite	39	..	..
Orthoclase and anorthoclase	16	35	33
Albite	..	..	3
Analcite	5	38	23
Thomsonite	Tr.	4	3
Natrolite			
Stilbite			
Titanaugite	11	3	3
Augite			
Aegirine-augite			
Hornblende	2	8	12
Biotite	4	5	13
Olivine	8	2	..
Apatite	5	2	5
Magnetite	8	2	4
Ilmenite			
Calcite, epidote, chlorite, serpentine, etc.	2	1	1

1. Typical analcite diabase.
2. Analcite syenite from dike west of Oil Well Ridge.
3. Analcite syenite from Oil Well Ridge.

Biotite, hornblende, olivine, apatite, ilmenite, magnetite, and other accessories show the same properties as those noted for the minerals in the diabase. Augite, on the other hand, clearly represents a more advanced stage of differentiation. Rather than an association with titanaugite, its euhedra show a slight zoning from grass-green cores to yellow-green rims, accompanied by a change in extinction angle from 43° to approximately 50°, $Z \wedge c$. The outer zones are faintly pleochroic from green to yellow-green, and doubtless contain certain amounts of the aegirine molecule.

The analcite is massive, with index slightly less than 1.490.

Thomsonite and natrolite are distinguished from the other zeolites by their parallel extinction. Stilbite is present as clear masses with traces of (010) cleavage. Its maximum extinction, $Z \wedge c$, is 8°.

This syenite presents a slightly later stage in the magmatic sequence than does the diabase. Titanaugite is absent, olivine is rare, hornblende is more abundant than augite, and the mafic minerals in general are less common. Deuteric action has entirely replaced olivine by carbonate, biotite shows evidences of extensive resorption, and the plagioclase is clouded with alteration products. Augite, though a relatively early mineral, is euhedral and fresh, as are the hornblende, apatite, and magnetite. Ilmenite is covered with a film of leucoxene. Rare idiomorphic intergrowths of analcite and biotite suggest simultaneous crystallization of these minerals; the analcite is common as interstitial grains.

The outstanding feature of all the specimens examined, however, is their extreme degree of zeolitization. Analcite, thomsonite, and natrolite replace the feldspars to varying degrees (Figs. 3, 4). Skeletal remains of unaffected material in a sea of invading zeolites are common features, and almost complete replacement is not rare. In the latter case, the original rectangular outlines of the feldspar crystals are preserved by bands of finely divided alteration products and remnants of unreplaced albite (?) which have formed around the margins. The controlling factors in establishing the loci of replacement seem to have been cleavage and fracture planes, although one case of sharply-defined hour-glass structure was noted (Fig. 4). The exact cause for this phenomenon is not clear, but there unquestionably has been some sort of selective replacement controlled by crystallographic directions within the feldspar.

That zeolitization continued far into the hydrothermal stages is indicated by the common occurrence of such minerals as the linings of vugs (Fig. 5). Of this same general period is late calcite, whose relations with the zeolites are not well shown.

Generally speaking, the analcite syenite shows remarkable similarities to rocks of the same name described by Gilluly[15] and Tyrrell[16] and to an analcite syenogabbro described by

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[15] Gilluly, James: Op. cit., pp. 199-211, 1927.

[16] Tyrrell, G. W.: On some dolerite sills containing analcite-syenite in central Ayreshire, Quart. Jour. Geol. Soc., Vol. 84, pp. 540-569, 1928.

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Knopf,[17] though individual mineral percentages do not exactly correspond.

PETROGENETIC INTERPRETATIONS.

The intrusive contacts between the analcite syenite stringers and the main diabasic mass on Oil Well Ridge suggest a composite character for parts of the igneous body. Further, it does not appear probable that the large analcite syenite core is a product of differentiation in place, because of its central location within the sill. This is an important difference from the otherwise similar occurrence in Ayreshire,[18] where the salic

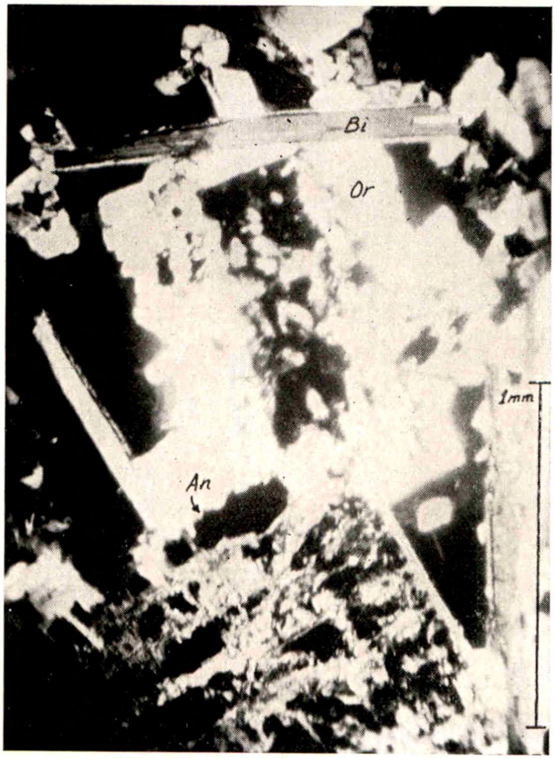

Fig. 3. x nicols. Replacement of orthoclase (Or, white) by analcite (An, black) in analcite syenite from Oil Well Ridge. Note the blade-like character of the biotite (Bi).

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[17] Knopf, Adolph: Op. cit., pp. 1774-1776, 1936.
[18] Tyrrell, G. W.: Op. cit., p. 564, 1928.

differentiate appears near the upper surface of the sill. The unmistakable structural and petrologic correspondence of the salic and mafic types, however, indicate derivation from a common magma source.

Combination and analysis of all available petrographic data give definite indications of three reaction series. One, the titanaugite—augite—aegirine-augite series, is continuous and best developed toward its sodic end. The second, a loose combination of continuous and discontinuous series, consists of labradorite—albite—anorthoclase—soda-rich orthoclase—analcite. The other is discontinuous, and is represented by magnesium-rich olivine—iron-rich olivine—ilmenite, magnetite—

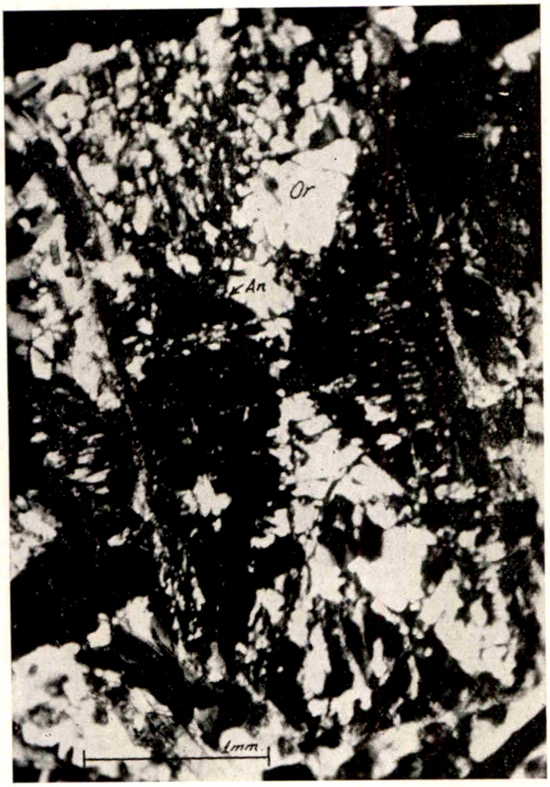

Fig. 4. x nicols. Hour-glass structure developed through replacement of feldspar by analcite. Note the euhedral character of the feldspar and the accumulation of unreplaced material around the crystal margin.

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hornblende, biotite—magnetite. Each member in a series is converted into the succeeding member by reaction with the residual magma. The net result is a gradual enrichment of the residuum in silica, water, and the alkalies, particularly soda, resulting in late crystallization of soda-rich orthoclase, analcite, and related species. The late lime (as present in the thomsonite and stilbite) is considered to have been derived from the calcic plagioclase through reaction with the magma. The composite diagram in Fig. 6 indicates the general age relations of all minerals recognized in the intrusions, with respect to one another and with respect to time.

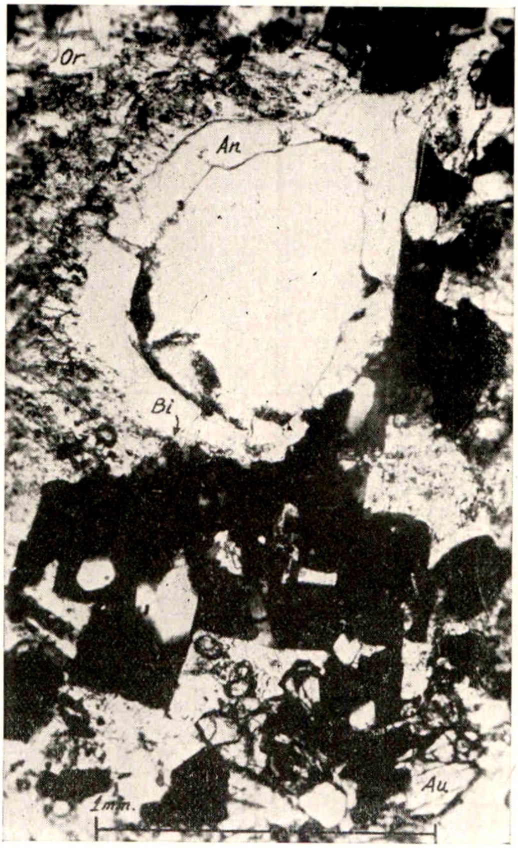

Fig. 5. Analcite (An) lining a small vug in analcite syenite. Euhedral augite (Au) and biotite (Bi) are surrounded by analcite and zeolites. In the upper left quadrant are large masses of partially analcitized feldspar.

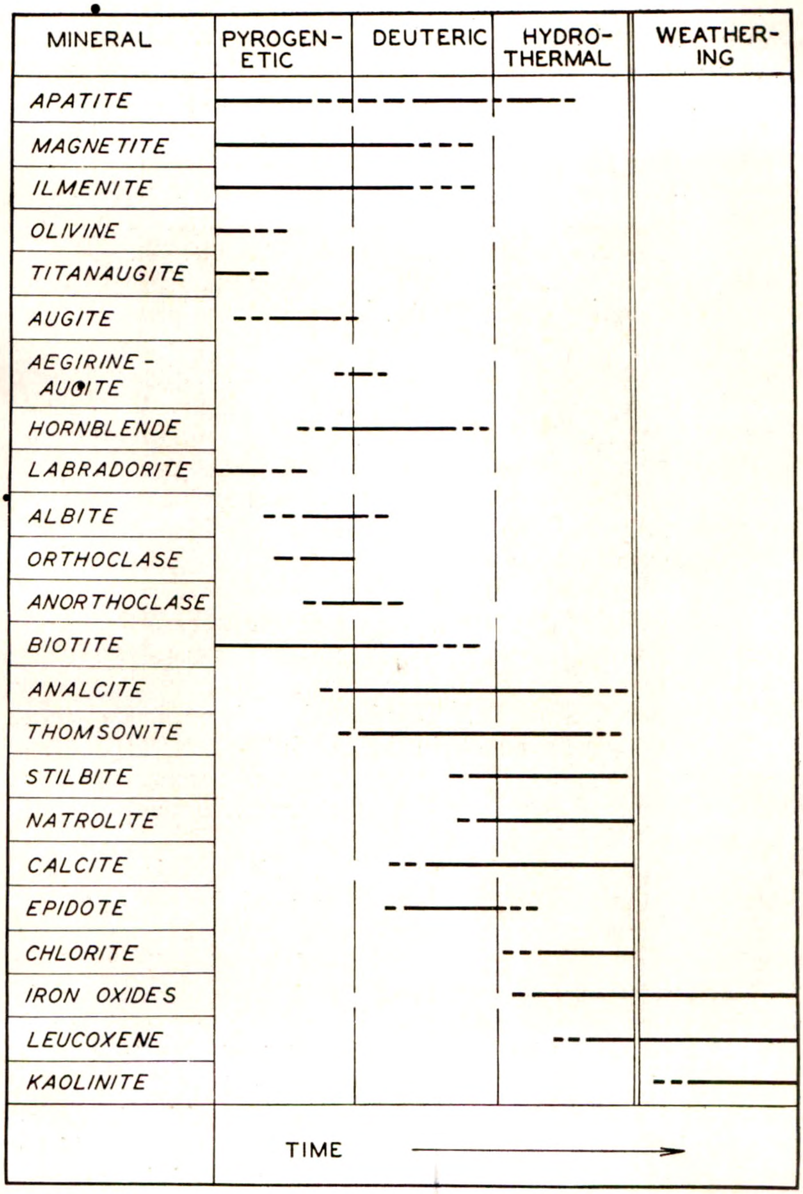

Fig. 6. Mineral age relations in analcite-bearing intrusives, South Park, Colorado.

The hypothesis advanced by the writer to explain the above phenomena, if the analcite syenite is actually intrusive into the diabase (a feature suggested but not proved by the field evidence), is essentially that given by Gilluly.[19] That the magma when first intruded was already in an advanced stage of differentiation is indicated by the early crystallization of biotite in rather large quantities. The magma was injected into the Mesozoic rocks as sills and discordant offshoots. In addition, a larger laccolithic, sill-, or stock-like body may be considered present at slightly greater depth. During crystallization of the ordinary sills and their offshoots, this mass would tend to develop a mass of olivine, ilmenite, magnetite, augite, and calcic plagioclase crystals, which would gradually sink in the mineralizer- and alkali-rich residual liquid.

Renewal of magmatic activity would inject this residuum into the overlying diabasic sills. Because these sills were cooling, but not yet completely solid, the later syenitic material followed the mushy zones (developing blended contacts) or fractures in the solid zones (where the contacts are sharp). Gilluly[20] explains the alkaline and water-rich character of the earlier intrusions—the analcite diabases in this case—as due to derivation, not from a primary source, but from a partially differentiated sub-magma. This hypothesis is not incompatible with the evidence available in the South Park cases; Gilluly's partially differentiated sub-magma would correspond to a differentiate of the "primary" quartz monzonite magma which lay west of Oil Well Ridge.

If, on the other hand, the analcite syenite core is a product of differentiation in place, there is no need for postulating a subjacent magma body. In such a case, the aplitic stringers would represent squeezed-out portions of the silicic differentiate.

The gradation without apparent break from the pyrogenetic to the hydrothermal stage is the most striking feature shown in these intrusions. That true magmatic injection took place at unusually low temperature is indicated by the narrow metamorphic zones in the surrounding sediments and by the abundance of primary analcite. Such low temperatures would be made possible by the mineralizer-rich character of the magma.

It becomes evident, then, that the analcite-bearing intrusives in South Park are excellent examples of rocks whose crystallization range actually lies astride that "point" where truly pyrogenetic processes give way to those considered hydrothermal. The conclusion to be made is essentially that proposed by Spurr and reiterated in a more immediate connection by Ross:[21] these features demonstrate "a closer genetic relation between igneous rocks on one hand and veins on the other than has often been recognized."

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[19] Gilluly, James: Op. cit., pp. 208-211, 1927.

[20] Gilluly, James: Loc. cit., 1927.

CHEMICAL COMPOSITION.

An analysis of a phase transitional between the true diabase and the more salic analcite syenite on Oil Well Ridge appears in Table 3. The other analyses are of the general "analcite diabase" type and the general "analcite syenite" type described by Gilluly and Tyrrell. That the South Park rock is a transitional type is evident from comparisons in the table. Those rocks grouped as analcite diabase are higher in ferrous iron,

TABLE 3.

Chemical analyses: Analcite-bearing rock from South Park compared with similar rocks from other occurrences.

	1	2	3	4	5
SiO_2	50.68	50.01	56.44	44.30	44.69
Al_2O_3	17.35	17.98	15.54	13.53	14.17
Fe_2O_3	4.16	3.05	3.27	4.11	3.35
FeO	3.07	3.26	3.67	5.46	10.86
MgO	3.31	3.13	1.73	10.48	6.41
CaO	4.70	7.09	4.16	10.82	10.28
Na_2O	5.90	4.43	5.81	3.13	3.64
K_2O	3.76	4.82	4.27	2.10	2.01
H_2O+	3.50	2.95	2.06	2.19	2.53
H_2O-	0.32	0.27	0.44	0.23	1.05
TiO_2	1.77	2.00	1.16	2.33	0.46
P_2O_5	0.89	0.67	0.83	0.58	0.45
MnO	0.19	0.10	....	0.10	0.31
BaO	0.28	....	....	....	Tr.
CO_2	0.04	0.09	0.97	0.12	0.00
	99.92	99.85	100.35	99.48	100.21

1. Analcite-bearing intrusive, South Park, Colorado; A. Willman, analyst.
2. Analcite syenite, near Emery, Utah; J. G. Fairchild, analyst. Gilluly, James: This Journal, Vol. 14, p. 205, 1927.
3. Analcite syenite, Howford Bridge, Mauchline; A. Dittrich, analyst. Tyrrell, G. W.: Quart. Jour. Geol. Soc., Vol. 84, p. 559, 1928.
4. Analcite diabase, near Emery, Utah; J. G. Fairchild, analyst. Gilluly, James: This Journal, Vol. 14, p. 205, 1927.
5. Olivine-analcite-dolerite (crinanite), Howford Bridge, Mauchline; A. Scott, analyst. Tyrrell, G. W.: Quart. Jour. Geol. Soc., Vol. 84, p. 557, 1928.

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[21] Ross, C. S.: A Colorado lamprophyre of the verite type, This Journal, Vol. 12, p. 224, 1926.

magnesia, and lime; lower in silica, alumina, and the alkalies. Those classed as analcite syenite are more nearly comparable, though they are slightly higher in silica and lower in soda. It is unfortunate that analyses of the other rock types on Oil Well Ridge are not available; doubtless they would lend themselves to computations of the type made by Gilluly[22] in strengthening his theory of differentiation in a subjacent magma chamber.

Under the C. I. P. W. system the rock classifies as a member of:

Class II ....Dosalic
Order 5 ....Perfelic — Germanare
Rang 2 ....Domalkalic — Monzonase
Subrang 4 ....Dosodic — Akerose

TABLE 4.

Norm and mode of analcite-bearing intrusive from South Park, Colorado.

Mineral	Normative	Modal
Orthoclase	22.2	26
Albite	37.7	14
Anorthite	10.0	9
Nepheline	6.5	..
Olivine (forsterite)	3.8	3
Diopside (magnesian)	3.0	..
Magnetite	5.3	5
Ilmenite	3.5	
Apatite	2.0	3
Hematite	0.5	..
Augite	...	6
Hornblende	...	6
Biotite	...	9
Analcite	...	15
Zeolites	...	3
Chlorite, kaolin, calcite, etc.	...	1

The norm is given in Table 4, and is compared with the accurately determined mode of the same rock. In view of the inflexibility of the chemical classification, the two correspond very satisfactorily. The extra soda and lime from plagioclase in the norm appear in zeolites and augite in the mode; the nepheline of the norm appears as zeolites in the mode; and the extra iron and magnesia of the norm appear in other ferromagnesian minerals of the mode.

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[22] Gilluly, James: Op. cit., pp. 206-207, 1927.

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THE ORIGIN OF APPALACHIAN DRAINAGE—A REPLY.

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ABSTRACT.

A critical analysis of a recently published theory of origin of Appalachian drainage from a system of southeastward flowing Permian consequents is presented. Questions as to the force of evidence set forth in support of the initial postulate, problematic relations of Triassic and present drainage, and especially, the failure of the theory to explain the positions or trends of major Appalachian streams, indicate that the new theory will not serve to replace the Johnsonian concept of regional superposition of Appalachian streams from a Cretaceous cover.

INTRODUCTION.

Major streams of the northern Appalachian region rise in the Allegheny Plateau and flow southeastward to the Atlantic directly across the northeast-southwest grain of rocks and structures ranging in age from pre-Cambrian to Tertiary. A century of investigation of the origin of this transverse stream system, and of related problems of Appalachian geomorphic development, has yielded results of far more than local importance; in a very real sense the northern Appalachians have occupied a unique position as a source place and proving ground for concepts which, first applied in that region, having come to be adopted throughout the world. Of the several theories of geomorphic evolution that have been proposed, the contrasted explanations of William Morris Davis (1889)[1] and Douglas Johnson (1931)[2] are best known, and serve to define two major stages in the history of the study. A third theory of drainage development, recently set forth by H. A. Meyerhoff and E. W. Olmsted,[3] differs markedly from the earlier views, and is incompatible with the theory of regional superposition of main transverse drainage lines that is embodied in Johnson's interpretation. It is the purpose of this paper to analyze the Meyerhoff-Olmsted theory, in an attempt to determine its merits as a possible alternative to Johnson's view, which is now widely accepted.

[1] Davis, W. M.: The rivers and valleys of Pennsylvania. Geog. Essays, Ginn and Co., New York, pp. 413-484, 1909.

[2] Johnson, Douglas: Stream sculpture on the Atlantic slope, Columbia University Press, New York, 1931.

[3] Meyerhoff, H. A., and Olmsted, E. W.: The origins of Appalachian drainage, This Journal, 5, Vol. 32, pp. 21-42, 1936.

THEORIES OF APPALACHIAN DRAINAGE DEVELOPMENT.

The Davis Theory. Davis believed that the southeastward flowing stream system of the Appalachian Ridge and Valley Province (Fig. 1) resulted from the reversal, by warping and capture during and before Triassic time, of an original northwestward flowing set of consequents[4] which had developed on the growing folds of the Permian Appalachians. In marked contrast, the streams of the Great Valley, Triassic Lowland and Piedmont Provinces (hereafter, for convenience, the Piedmont district), were thought by him to belong to a younger system of consequents, initiated with southeastward courses on a former inland extension of a Cretaceous coastal plain, and later superposed across the complex structures of the region. He held that the Cretaceous mantle from which the Piedmont streams were let down had rested directly on the present hilltop peneplane, the Schooley, which was regarded by him as Jura-Cretaceous in age because it appeared to pass under Cretaceous beds at the Fall Zone. Davis thus recognized two distinct generations of streams in the area as a whole, those of the Ridge and Valley Province being traceable back to initial Permian fold-mountain consequents (but now so greatly modified by capture that little semblance of the original pattern remains), and those of the Piedmont district, including the lower reaches of trunk streams, to a system of Cretaceous coastal plain consequents.

The Johnson Theory. Johnson has presented evidence tending to prove (1) that the captures and reversals postulated by Davis in explaining the evolution of the present drainage pattern in the Ridge and Valley Province from Permian fold-mountain consequents are highly improbable; (2) that certain stream relations in the region of Davis' superposed drainage cannot be explained by direct superposition from a mantle resting on the present hilltop peneplane; (3) that the erosion surface (the Jura-Cretaceous Fall Zone peneplane) which passes beneath the Cretaceous beds at the present inner margin of the coastal plain would, if projected inland, arch well above the surface of the Schooley peneplane, and, (4) that the Schooley surface is Tertiary in age. He has proposed the view that all of the preexisting streams of the area as a whole, of whatever origin or pattern, were destroyed by a widespread extension of the Cretaceous coastal plain across the surface of the Fall Zone peneplane. A southeastward flowing stream system, initiated on the uparched Cretaceous depositional surface, was modified by capture during the stripping back of coastal plain strata early in the Schooley cycle, was further modified in a new series of adjustments after the streams had been let down across structures of the older rocks later in the Schooley cycle, and in post-Schooley time.

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[4] Davis: Op. cit., p. 449. Davis did not hold, as Meyerhoff and Olmsted state in their discussion of his views, that the Permian drainage of the Pennsylvania region was antecedent.

The Meyerhoff-Olmsted theory. The Meyerhoff-Olmsted theory will be discussed fully in the pages which follow; it is outlined here briefly so that the plan of treatment adopted in this paper will be understood. These workers hold that the present southeast flowing stream system of the Ridge and Valley Province and the Piedmont district was inherited directly from a single system of southeast trending, late Permian consequents, whose positions and directions of flow were controlled by the slopes of the surface produced by Appalachian folding. The theory is based (1) on evidence which is supposed to prove that the Permian drainage divide was in the Ridge and Valley Province, rather than in the Piedmont, as Davis believed; (2) on a close correspondence between the positions of present major streams and the positions of the streams which carried waste into Triassic fault basins, this correspondence being supposed to prove that the present streams date from Triassic or pre-Triassic time, rather than from the Cretaceous, as Johnson believes; and (3) on a correlation of locations of present southeast flowing streams with major transverse synclinal axes in the fold mountain belt, and with other transverse structures and zones of weakness, which would account for the positions of the streams without recourse to regional superposition from a Cretaceous coastal plain. These propositions will be discussed in the order named.

POSITION OF THE PERMIAN DIVIDE.

Analysis of Arguments. Meyerhoff and Olmsted devote a considerable part of their paper to presentation of evidence which, they hold, indicates that the Permian streams of the Appalachians *must* have flowed to the southeast. In this connection they state:—(1) that "the Blue Ridge . . . was the backbone of Appalachian uplift," and again, (2) "that the

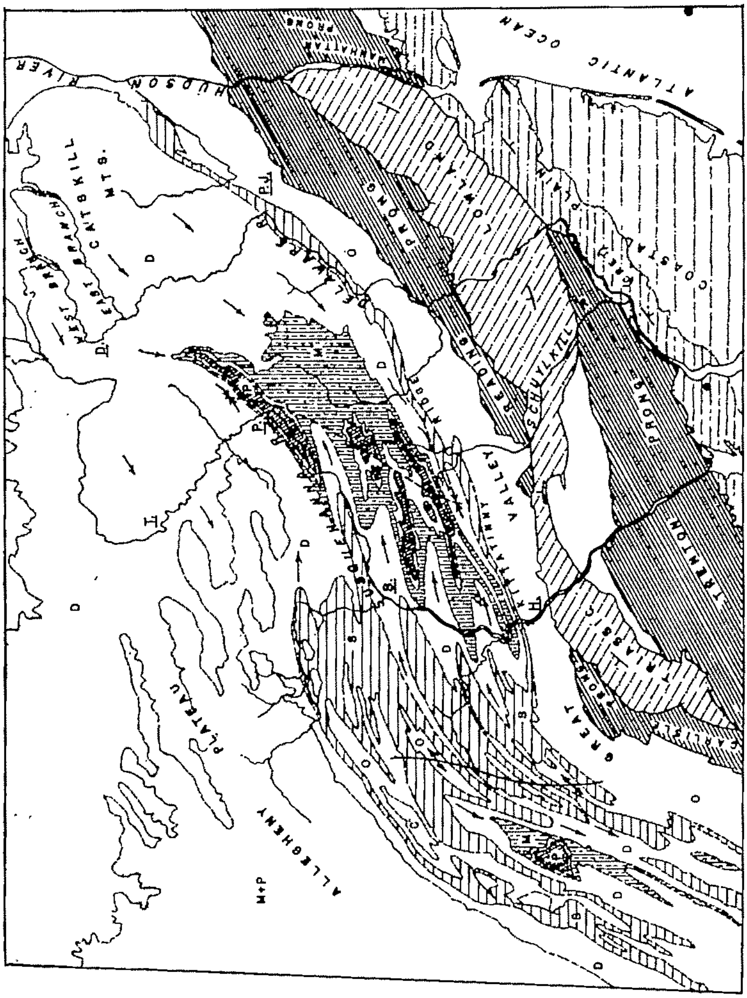

Fig. 1. Map of the Northern Appalachian region, from the Geological Map of the United States (1932). The Ridge and Valley Province is the fold mountain belt between the Allegheny Plateau and Kittatinny Ridge. The "Piedmont district" includes the Great Valley, four Prongs of lower Paleozoic and pre-Cambrian crystallines and metamorphics, and the Triassic Lowland. Carlisle Prong is the northern extension of Blue Ridge. Initial letters of names of Paleozoic periods indicate the age of rocks in the Ridge and Valley Province. Direction of pitch of folds is shown by arrows, and the positions of transverse anticlinal and synclinal axes are indicated by solid and dashed lines, respectively. Underlined letters in heavy type mark the location of cities mentioned in the text: D, Deposit; T, Towanda; P J, Port Jervis; S, Sunbury; H, Harrisburg.

highest elevations and the drainage divide of the late Permian and early Triassic Appalachians was situated no farther east than the more or less continuous range formed by Blue Ridge, Reading Prong, and the Green and Taconic Mountains,"[5] and again, after several explanatory paragraphs which are treated below, (3) that "the axis of maximum uplift and the Permo-Triassic watershed are believed to have been located northwest of Kittatinny Ridge, but not as far as the southeastern front of the Allegheny Plateau."[6]

Statements 1 and 2 are supported by a discussion of the bearing of the structure and Paleozoic stratigraphy of the Piedmont district on the form of the initial constructional surface of that region. The conclusion, that the highest lands of Permian time were located somewhere in the Piedmont crystalline belt, is the traditional American view; it is in all essential respects identical with the concept that caused Davis to direct the Permian drainage of the Ridge and Valley Province northwestward, in spite of the manifold difficulties which this postulate introduced into his scheme of drainage evolution. Since this conclusion automatically limits the possible extent of southeast drainage of the Permian lands to the southeastern part of the Piedmont district, it is directly opposed to the major thesis of the Meyerhoff-Olmsted article.

It appears, therefore, that statements 1 and 2 must be regarded as intermediate steps[7] in the Meyerhoff-Olmsted structural argument, and that statement 3, which places the Permian divide farther to the northwest, must be considered the fundamental postulate of the theory. This change in the location of the divide from the Piedmont to the Ridge and Valley Province, that is, to a position somewhat more favorable to the development of an extensive southeasterly directed consequent drainage system, is based, (A) on the prevailing northwest asymmetry and overturning of Appalachian fold structures, *and* (B) on hypothetical extension of low angle thrust plates northwest across an undefined part of the Ridge and Valley Province.[8] It is at once evident that these two explanations are mutually exclusive, rather than cumulative, in their effect on the trend of drainage lines at any one place at the time of mountain building; the same stream cannot be at once consequent on folded strata and consequent on a thrust plate that covers the folds.

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[5] Op. cit., p. 27.

[6] Op. cit., p. 29.

[7] Meyerhoff, H. A.: personal communication.

[8] Op. cit., p. 27-29.

(A) Asymmetry or overturning of a single fold may well control the position of the *local divide*[9] formed by the fold in its growth, the theoretical distance of shifting of the initial divide from the present outcrop of the axial plane of the fold being a function of the dip of the axial plane and the initial height of the fold crest above the present erosion surface. The problem under discussion relates, however, not to a local divide, but to the main divide of the Appalachian region as a whole, and there is no evident reason why asymmetry of many folds should cause an appreciable shifting in the position of the major divide of the fold mountain belt. All of the major transverse streams of the Appalachians cross many folds.

(B) Low angle overthrusts and other structures indicating considerable horizontal translation of rock masses have been mapped in the Hudson Valley and Piedmont districts. The existence of some of the major thrusts is a problem now under discussion. Even if the faults are present as mapped, there is no structural or stratigraphic evidence that any of those described in the Pennsylvania Piedmont ever extended northwestward to or beyond the position of Kittatinny Ridge. Finally, the dates of the supposed low angle thrusts are largely unknown.

Meyerhoff and Olmsted's tacit assumption that the initial drainage of hypothetical Permian overthrust sheets flowed southeast appears to be based on a belief that the initial surface of a thrust mass necessarily slopes in the same direction as the dip of the fault plane. In some simple bedding thrusts this relation may be true, but it seems improbable that it would hold in internally complex thrust masses rooted in the metamorphic terranes of the Piedmont district. Structure sections of the Alps and the Scottish Highlands support the alternative suggestion that, because of a piling up or slicing of thrust plates, the height of land and the drainage divide at the time of faulting might be many miles back from the edge of the most extended thrust plate. Moreover, it seems highly questionable whether the initial drainage of the translated sheet or sheets of southwest-striking metamorphics would exhibit the parallel southeast stream trends that characterize the present Atlantic slope.

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[9] Meyerhoff and Olmsted: Op. cit., fig. 2.

These uncertainties as to the former extension of thrust plates over the folds of the Ridge and Valley Province, and the problematic effect of such thrusts, and of asymmetric folds, on the trend of consequent drainage at the time of mountain building, raise a decided question as to the force of the arguments presented by Meyerhoff and Olmsted as the "structural basis" of their statement No. 3, "that the axis of maximum uplift and the Permo-Triassic divide were located northwest of Kittatinny Ridge."

Surface form of the Permian Appalachians. Restoration of the initial surface of an orogenic belt, on the assumption that major structures at the present erosion level had distinct topographic expression on the first surface of uplift, is a highly complex problem even under the most favorable circumstances. Davis[10] and Chamberlain,[11] who attempted to reconstruct Appalachian folds on the basis of the structural relations of their truncated roots, confined their efforts to the Ridge and Valley Province, where the relatively simple form of folds controlled by massive middle and upper Paleozoic quartzites makes application of the method feasible. Extension of the same method to the complex mountain belt southeast of Kittatinny Ridge is complicated: (1) by uncertainty as to the original thicknesses and stratigraphic relations of the intensely deformed early Paleozoic beds that now underlie parts of the Piedmont district, (2) by the presence of a major unconformity between these beds and the upper Paleozoic strata that may have formed the Permian surface, (3) lack of knowledge as to the dates of structures in the Piedmont, and consequent uncertainty as to which of the structures might have had a controlling influence on the Permian surface, and (4) the fact that the rocks of the area have been displaced by vertical movements amounting to thousands of feet in post-Permian time, especially during the Triassic, and consequent doubt as to how much of the present altitude of any given stratigraphic horizon must be ascribed to Permian, as opposed to post-Permian, movements.

Conclusions. It appears, therefore, that even the most generalized restoration of the Permian surface in the Piedmont region, on the basis of structures at the present erosion level, is impossible. Discussion of other lines of evidence bearing on the broader problem of the relative height of the Piedmont and the Ridge and Valley districts during Permian time consists largely of a balancing of indefinite possibilities and probabilities which do not, in this paper, merit the space they would occupy. The conclusion, which is largely negative, may be stated briefly: The weight of indirect evidence and deductive reasoning favors the generally accepted view that the highest lands of the Permian Appalachians were in the intensely deformed belt southeast of Kittatinny Ridge, but this view is not susceptible to direct proof. It is impossible to state that Permian drainage of the growing Appalachians *must* have been either consequent or antecedent, or that it *must* have flowed to the northwest or to the southeast. It is possible that the initial system was consequent, and it is possible that some or all of the drainage of the Ridge and Valley Province escaped southeast to the Atlantic, as required by Meyerhoff-Olmsted theory. But these possibilities certainly cannot be considered as part of the "structural basis" of an Appalachian drainage theory.

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[10] Op. cit., pp. 449-453.

[11] Chamberlin, R. T.: The Appalachian folds of central Pennsylvania, Jour Geol., Vol. 18, pp. 228-251, 1910.

Almost complete lack of knowledge of Permian surface form does permit a wide range of postulates as to initial drainage *direction*. But the crux of the problem of the origin of Appalachian drainage is the explanation of numerous parallel southeast trending segments of major streams, which show a complete disregard for rock structures. It should be especially noted that in seeking to derive this pattern from a system of Permian consequents Meyerhoff and Olmsted *assume* that the Permian streams had numerous parallel southeast trending segments. They do not explain why this should have been so.

TRIASSIC DRAINAGE.

General Statement. Each of the streams of the Northern Appalachians, on its way to the sea, crosses the outcrop of the thick sequence of Triassic shales and sandstones preserved in downfaulted basins in the Pennsylvania and New Jersey Piedmont (Fig. 1). According to Meyerhoff and Olmsted, an extraordinary correlation between the positions of these present streams and the positions of Triassic streams (as denoted by the lithology of Triassic beds along the northwestern border of the fault basins), indicates that the southeastward flowing streams of the Atlantic Slope occupied their present position in

Newark (Triassic) time.[12] This relationship, if true, would tend to support the theory of preserved Permian drainage; in such measure as the degree of matching might exceed that which would be expected on the basis of chance, it would be unfavorable to Johnson's theory of superposition of present streams across the Triassic belt from a Cretaceous coastal plain. The correlation is said to be so striking that Johnson's theory is untenable.

It is by no means certain that the Newark series as a whole was deposited by southeast flowing streams. Partly because of an abundance of mica and feldspar in the Triassic sediments, Stose has argued that the bulk of the materials were derived from crystalline terranes to the southeast of the fault basins, rather than from the Paleozoic beds which underlie the region to the northwest. He believes that the Newark beds were laid down in basins that deepened westward as deposition continued, and that it was only during the latter part of Newark time that uplift to the northwest formed highlands from which were shed the quartzite and limestone conglomerates which occur along the western side of the basins.[13] It appears that this conclusion, based on extensive field work, should not be lightly set aside,[14] but no attempt is made here to weigh the merits of the problem of the derivation of the Triassic sediments. It is sufficient to point out that Stose's conclusions, if even partly correct, are fatal to the theory of pre-Triassic origin of present Appalachian streams.

Relations of Major Streams. Meyerhoff and Olmsted's strongly worded conclusions as to the correlation between the positions of Triassic and present streams are based on supposed localization of conglomerates in the Triassic sequence at points where modern streams enter the Triassic belt. In the case of the Susquehanna they state that:

> "In one outcrop three and a half miles east of Yellow Breeches Creek near Susquehanna River, an exceptionally wide stratigraphic range is represented in the constituents of the (Triassic) conglomerates, and every fragment can be traced to its source in the

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[12] Op. cit., p. 39.

[13] Stose, George W.: Description of the Fairfield and Gettysburg quadrangles. U. S. Geol. Surv., Atlas. Fairfield-Gettysburg Folio. No. 225, 22 pp., 1929. For stratigraphic relations of the conglomerates see also: McLaughlin, Dean B.: The thickness of the Newark series in Pennsylvania and the age of the border conglomerate. Mich. Acad. Sci., Papers, Vol. 16, pp. 421-427, 1931.

[14] Meyerhoff and Olmsted: Op. cit., p. 37.

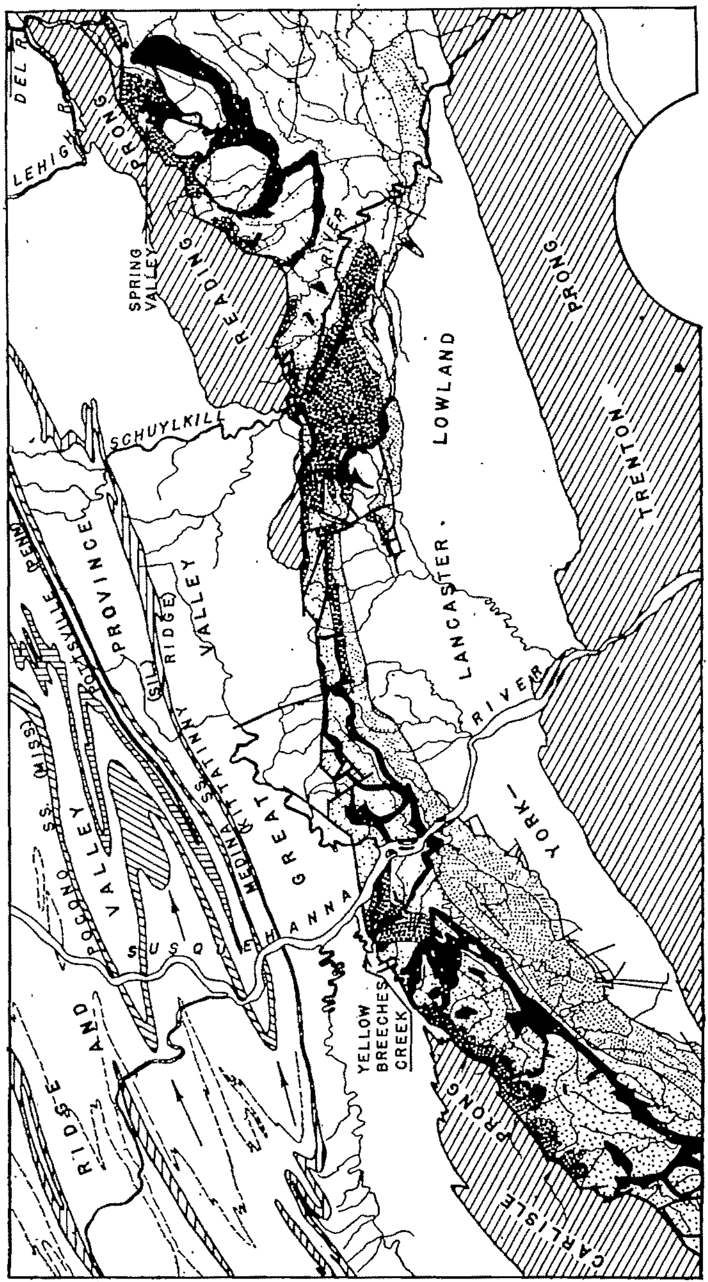
DEL R
LEHIGH R
PRONG
READING
SPRING VALLEY
RIVER
SCHUYLKILL
LOWLAND
PRONG
TRENTON
0
5
10 MILES
LANCASTER
RIVER
YORK
POTTSVILLE (PENN)
PROVINCE
(SIL) RIDGE
VALLEY
MEDINA SS
KITTATINNY
GREAT
POCONO SS. (MISS)
VALLEY
SUSQUEHANNA
RIDGE AND
YELLOW BREECHES CREEK
CARLISLE PRONG

Fig. 2.

several Paleozoic formations through which the Susquehanna has cut its way."[15]

Triassic conglomerates, interbedded in a sequence that consists predominately of shale and sandstone, do occur just southeast of the Triassic border fault in an area extending from three to five miles west of the Susquehanna (Fig. 2). There is no doubt that the quartzite pebbles were derived from the Paleozoic sequence to the northwest, but it is not clear how the "stratigraphic range" represented by the pebbles (which bears on the length of the depositing stream) was determined. In an earlier study of Susquehanna River terraces[16] the writer found that the range of lithologic types in each of the three great Appalachian quartzites and in other sandstones in the Paleozoic sequence was such that not more than one per cent of the quartzose pebbles in terrace deposits could be traced, by sight identification, to any specific source bed.

As pointed out in the direct statement and in the quotation above, these Triassic conglomerates are found west of the Susquehanna Valley. Quartzite pebbles are, however, notably rare in numerous stream cuts and road cuts *in* the Susquehanna Valley, where Triassic sediments adjacent to the boundary fault are predominantly fine shales and sandstones. If conglomerates serve as an index to the location of Triassic streams, it appears that no stream occupied the present position of the Susquehanna during the deposition of this shale-sandstone sequence. There is no modern cross-cutting stream to match the conglomerates west of the Susquehanna Valley.

[15] Op. cit., p. 38.

[16] Mackin, J. Hoover: Terraces in the Susquehanna Valley below Harrisburg, Pennsylvania, Science, Vol. 80, p. 141, 1934.

Fig. 2. Map of southeastern Pennsylvania, from Geological Map of Pennsylvania (1931). The three ridge-forming quartzites of the Ridge and Valley Province are named, and the direction of pitch of the folds in which they are involved is indicated by arrows. The Great Valley and the York-Lancaster Lowland are underlain, in large part, by weak lower Paleozoic shales and limestones; the Carlisle, Reading, and Trenton Prongs, by resistant lower Paleozoic and pre-Cambrian crystallines and metamorphics. Triassic sediments, indicated by a stippled pattern, rest unconformably on the older rocks along the southern margin of the Triassic Lowland, and are in fault contact along the northern margin. Triassic igneous rocks are indicated by solid black, shales and sandstones by a light stipple, "quartzose conglomerates" by a dark stipple, and "limestone conglomerates" by small circles. The symbols give an erroneous impression of the distinctness of the several lithologic units; mapping of the "quartzose conglomerates," in particular, appears to have been based on a litter of pebbles in soil, and large areas are so mapped where fresh road cuts show uniformly fine shales and sandstones.

Meyerhoff and Olmsted do not discuss the lithology of the Triassic sequence at the point where the present Schuylkill River enters the Triassic lowland; a fan shaped area of "quartzose conglomerates,"[17] depicted on the Pennsylvania geologic map (Fig. 2), suggests that a large stream discharged into the Triassic basin of deposition in the vicinity of the present Schuylkill *when these pebble-bearing beds were being formed*. But, if conglomerates mark the location of Triassic streams, no stream could have followed the present course of the Schuylkill at another time, during the deposition of a thick sequence of fine shales and siltstones, without pebbles, which outcrop *in* the Schuylkill Valley near the border fault. Most significant of the Triassic sediments of the Schuylkill area are a series of limestone and dolomite fanglomerates, at least 1,000 feet in thickness, which occur at the exact point where the river issues from the Reading Prong.[18] Steep dips and complex structures of Paleozoic strata northwest of the boundary fault indicate that a Triassic stream heading any considerable distance in these terranes would have crossed the outcrop of both quartzites and limestones; the absence of quartzite pebbles in the limestone fanglomerates, and the angularity of the limestone blocks, indicate that they were laid down by a local stream, probably at the foot of an active fault scarp. This local stream built its fan at the point where the Schuylkill now crosses the boundary fault. The essential conclusion, to be drawn from the occurrence of these three markedly different rock types in the Schuylkill area, is that local conditions of sedimentation varied widely from time to time during the Triassic, and that no single Triassic stream maintained a course in any way comparable with that of the Schuylkill throughout the deposition of the Newark series.

Apparently in connection with the Lehigh River, Meyerhoff and Olmsted state:

> "One large deposit of quartzite conglomerates situated south of Spring Valley, Pennsylvania, is not associated with a modern river, but its position south of the broad gap at Bethlehem leaves no doubt as to its origin and initial fluvial connections."[19]

The inference is that the Spring Valley conglomerates were formed by the Triassic Lehigh River, and that the stream has been captured by the Delaware during the present erosion cycle (Fig. 2). Whether or not the Lehigh River cut the broad gap south of Bethlehem seems open to question, for the gap lies along the outcrop of Paleozoic limestones infolded in the resistant rocks of the Reading Prong, and may well owe its existence to the etching out of these weak rocks by minor streams. Nevertheless, the sharp elbow of the Lehigh may be an elbow of capture, and that stream may well have once flowed southeastward toward the Spring Valley area, either through the Bethlehem gap, or at some level above the Schooley peneplane. But the lithology of the Spring Valley Triassic sequence does not, in the opinion of the writer, serve to prove that the Lehigh occupied such a course during Triassic time, for, in addition to quartzose conglomerates, the Spring Valley deposits include shales, limestone conglomerates, and talus and landslide breccias. It is, in other words, a typical border sequence, and can be duplicated in closely spaced unit areas along the full length of the western margin of the Newark belt.

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[17] Geologic map of Pennsylvania. Harrisburg, 1931.

[18] Geological map of Pennsylvania.

[19] Op. cit., p. 38.

Relations of Minor Streams. A close correspondence between distribution of Triassic conglomerates and the positions of certain minor streams which enter the Triassic area from the northwest proves, according to Meyerhoff and Olmsted, that these streams date from Triassic time. No specific cases are described. The fact that the minor streams are closely spaced and that, as stated above, conglomerates of various types are continuous for the greater part of the distance along the western margin of the Triassic Lowland makes the use of this criterion in the case of the small streams even more difficult than in the cases of the major streams. Distribution of conglomerates shown on the Pennsylvania state map, and especially on detailed quadrangle maps of the Pennsylvania and United States Geological Surveys, fails to show any consistent relationship; none was found by the writer in five days field work along the fault front.

The trend of present minor streams provides an alternative approach to the problem of their origin, for if they date from Triassic time they should flow southeast from upthrown blocks of older rocks to downthrown blocks of Triassic sedimentation. Where the Triassic beds are in fault contact with resistant crystallines of the Reading Prong most minor streams do flow southeastward, down the slope of the resequent fault line scarp that has been developed by selective erosion of relatively weak Triassic sediments. Where Paleozoic limestones of the upthrown blocks have been reduced to a lower level than the Triassic shales many of the minor streams flow across the fault in the opposite direction, from downthrown to upthrown blocks. These small streams could not have flowed northwestward throughout Triassic time.

Yellow Breeches Creek, mentioned by Meyerhoff and Olmsted in a paragraph quoted above, flows for many miles directly along the trace of the boundary fault, crossing and recrossing the fault line (Fig. 2). This stream, and the many other northeast-southwest trending streams of the district, could not have occupied their present course during the Triassic.

These relations, and the trellis drainage pattern that is well developed in parts of the Triassic Lowland, indicate that most of the minor streams of the area as a whole owe their positions and directions of flow to headward erosion (in post-Triassic time) controlled by differential rock resistance.

Conditions of deposition along the western margin of the Newark Basin. Juxtaposition of talus breccia, conglomerates and fanglomerates of many types, and fine shales, at the present erosion surface in small unit areas near the western margin of the Triassic Lowland is due to shifting of different stratigraphic horizons to a common plane (the present surface) by minor block fault movements of Triassic date. Wide variation in the rock types that would appear in a columnar section of the Triassic beds near the fault, taken together with local fault zones showing intense crushing of Triassic sediments, prove that movements on the major boundary faults were recurrent and that conditions of deposition varied widely during the accumulation of the Newark sediments. Laminated shales are now in fault contact with ancient rocks at many points. Since these shales could not have been deposited at the base of active fault scarps, it appears that, during some stages of Triassic sedimentation, the western border of the basin of deposition was some distance west of the fault zone which marks the present western boundary of the Triassic Lowland.[20] During such stages any streams entering from the northwest would have wandered widely over alluvial plains, and could not have maintained fixed positions at what is now the western boundary of the Lowland.

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[20] For independent stratigraphic evidence leading to the same conclusion see Stose, G. W., and Jonas, A. I.: Triassic sedimentary rocks and basaltic flow northwest of Lebanon, Pennsylvania. Bull. Geol. Soc. Am., Vol. 36, pp. 160-161, 1925 (abstract).

Longwell, and others, present evidence of beveling, and renewal by recurrent faulting, of the Triassic scarps at the east margin of the Connecticut lowland. Longwell, C. R. Notes on the structure of the Triassic rocks in southern Connecticut. This Journal, 5, Vol. 4, p. 235, 1922.

Conclusions: (1) Study of the sedimentary sequence along the northwestern margin of the Triassic Lowland fails to confirm Meyerhoff and Olmsted's statement as to the striking correlation between distribution of Triassic conglomerates and the positions of present streams, major or minor. The seemingly rigid test of channel for channel correlation, utilized here in the cases of the major streams, is the only test known to the writer that can be applied to the statements of Meyerhoff and Olmsted. Conglomerates of several types occur at many points, at and between streams, but, in a sequence that consists of interbedded shales, sandstones, conglomerates and breccias, the mere proximity of a Triassic gravel lens to a present stream means nothing. (2) Consideration of conditions of deposition of the varied Triassic sequence indicates that all streams which entered the basin of deposition from the northwest must have shifted their courses markedly, from time to time, at the western boundary of the present Triassic Lowland, which did not always correspond with the western margin of Triassic sedimentation. The distribution of conglomerates at the western boundary of the present Triassic Lowland does not, therefore, serve as a reliable index to the entry points of streams flowing into the Triassic basin of sedimentation; in so far as the conglomerates are concerned, the present major streams of the Ridge and Valley province might, or might not, have occupied their present positions during Triassic time.

Relations of conglomerates in the Newark sequence do not (1, above), and could not (2, above), prove or disprove the thesis that the present major streams of the Atlantic slope date from a system of southeastward flowing Permian consequents.

RELATIONS OF APPALACHIAN STREAMS TO STRUCTURE.

General statement. Meyerhoff and Olmsted's statement of their theory as one which holds that the modern drainage of the Atlantic slope evolved directly from the original consequent system which drained the Permian Appalachians leaves much to be desired in the way of clarity, for in the long course of post-Permian erosion major streams might have retained their original courses with little essential change, or they might have been so completely modified by capture and other adjustments that little or no trace of the initial pattern is preserved. The problem is not solved by their treatment of individual streams. They suggest: (1) that the Susquehanna (as indicated by structural relations) is an inherited Permian consequent in the Ridge and Valley Province and in the Piedmont[21]; and, (2) that all minor streams which cross Kittatinny Ridge were let down across present structures from the backslope of an asymmetrical fold, or from a hypothetical overthrust sheet,[22] but that the Susquehanna and other major streams which cross the ridge may have gained their courses by subsequent erosion guided by transverse zones of weakness.[23] Since a single stream, in the same ridge crossing, cannot be at once consequent and subsequent, it appears that two distinctly different theories are proposed. The theory which holds that the present major transverse streams are inherited Permian consequents is generally favored in the Meyerhoff-Olmsted article, and will be examined first.

Tests of the theory of preserved Permian consequent drainage. The first and most obvious test of the theory that Appalachian streams inherited their courses directly from a system of Permian consequents is a comparison of the positions of present stream courses with the positions that should have been occupied by major streams on the Permian surface, restored on the basis of present structures. This test is predicated on the basic assumption on which the theory itself is founded, namely, that structures at the present erosion had sufficient topographic expression on the Permian surface to produce and control a consequent pattern. It is evident from the foregoing discussion of the problem of the Permian divide that the test can be applied only in those parts of the Appalachians where the upper Paleozoic sequence is sufficiently preserved to make the restoration practicable. The Ridge and Valley Province of eastern Pennsylvania, where the contrasted theories of Davis, Johnson and Meyerhoff and Olmsted have been applied, meets this requirement.

In such a region we might expect that major transverse consequents should cross belts of folds in or near transverse sags in the folded structures, if such structural sags are present. The value of this test depends on whether a given structural sag was reflected in the initial surface. Since, as pointed out above, the whole concept of consequent drainage is based on the assumption that larger structural elements did have sufficient surface expression to control drainage ways, it appears that the correspondence or lack of correspondence of stream courses with well marked structural sags is a valid test of the consequent theory. It must be applied, of course, only to major streams which cross a number of folds, for local crossings of single limbs of asymmetric folds may be due to local superposition or other accidents.

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[21] Op. cit., p. 31.
[22] Op. cit., p. 34.
[23] Op. cit., p. 32.

Streams or segments of streams which flow parallel with fold structures need not be expected to occupy synclinal valleys, for the axial planes of many Appalachian folds are inclined, and a shifting of a longitudinal synclinal consequent to a homoclinal or anticlinal position, without capture or other interruption that would destroy the identity of the stream, is entirely possible. But if such longitudinal streams be true consequents, they should flow in the direction of the *pitch* of related structures, provided only that the structural pitch is of such amount that convergence of horizons higher in the sequence could not have eliminated its effect on initial surface slopes. If, in a closed structure, pitch is marked and continuous for any considerable distance, the direction of flow of inherited consequent streams must correspond with it.

With these considerations in mind, we may examine the specific cases advanced in support of the theory of preserved consequent drainage:

RELATIONS OF LONGITUDINAL STREAMS TO STRUCTURE.

The East and West Branches of the Delaware River, the headwater reaches of the Susquehanna, and a segment of the Susquehanna between Pittston and Sunbury (P and S, Fig. 1) flow southwest from the Catskills along the trend of fold structures. In 1933 Ruedemann suggested that these streams had inherited their courses from a set of southwestward flowing synclinal consequents, the "ancestral Susquehanna system," of Permian age.[24] He believed that the present southeast flowing master stream of the region, the Delaware River, had extended itself headward from the Atlantic by a series of captures, the most recent of which had gained for that stream its East and West Branches at the expense of the Susquehanna system. Mackin replied to Ruedemann's paper, comparing the theory of preserved synclinal consequent drainage with Johnson's theory of regional superposition, and concluding that the latter theory provided the better explanation of the drainage pattern in question.[25] The reply was sent to Ruedemann before publication and benefitted greatly by the incorporation of suggestions and corrections offered by him in the most cordial spirit. The Meyerhoff-Olmsted treatment of Delaware-Susquehanna problems in the area under consideration must be quoted in full:

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[24] Ruedemann, Rudolf: Development of Drainage of Catskills, This Journal, 23, 337-349, 1932.

> "The adherents of the theory of regional superposition dismiss Appalachian structure as the initiating factor in localizing modern stream courses and as a determinant of the present geomorphic pattern, although in doing so they must ignore many structural and stratigraphic facts of fundamental importance. This is evident in Mackin's attack on Ruedemann's exposition of southwest drainage from the Catskill Mountains. In the first place, it may be questioned whether Ruedemann intended to imply that the present streams are longitudinal consequents; they are subsequents, as Mackin postulates, but there is more reason to believe in their derivation from post-Permian longitudinal consequents than Mackin realizes. There has been deep erosion in the Catskills, yet the late Devonian still rises to heights approximately 4,000 feet. In the Pocono Plateau, 130 miles to the south, the early Mississippian conglomerate which caps the plateau surface has a peak elevation of 2,300 feet, and at this point the Upper Devonian lies approximately 3,000 feet lower than in the Catskills. Granting that the thickening of the Lower Mississippian deposits southward tends to make the stratigraphic relief greater than the original topographic relief, none the less, the doming of the Catskill country and the sagging of the Pocono-Susquehanna section was sufficiently marked to decant Catskill drainage in the latter direction, regardless of the behavior of individual folds or their specific relations to present streams. But this obvious and plausible explanation of a local situation has been discarded in favor of complicated fluvial jockeying in a theory wherein the local geology weighs so lightly."[26]

It should be noted in passing that the age of the sandstone beds of the Catskill-Pocono region is a problem now under discussion; Chadwick[27] has advanced evidence tending to prove that the capping sandstones of the Catskills are middle, rather than late Devonian, and that the so-called Mississippian Pocono may be Devonian in age. There is an additional question as to how much of the southwest dip of the beds must be attributed to "doming of the Catskill country" and how much may be the initial slope of deposition of the stream laid sandstones and conglomerates of the Catskill-Pocono region. These questions do not alter the fact that there is a regional dip (or, more properly, regional pitch of broad folds) southwest from the Catskills, but they may alter the amount of the dip that must be ascribed to Permian movements.

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[25] Mackin, J. Hoover: The evolution of the Hudson-Delaware-Susquehanna drainage. This Journal, 26, pp. 319-331, 1933.

[26] Op. cit., p. 29.

[27] Chadwick, G. H.: What is "Pocono"?, This Journal, 5, Vol. 29, pp. 133-143, 1935.

The streams of the southwestern Catskills, particularly the East and West Branches of the Delaware and the headwaters of the Susquehanna, flow parallel with, and down the pitch of structures of Permian age. Meyerhoff and Olmsted, in accepting the fact that the streams flow in the same direction that would have been taken by Permian consequents as an indication that the streams date from Permian time, fail to appreciate the full significance of their statement that these streams are subsequents. If the streams are subsequents they extended themselves headward along weak rock belts and should, for this reason alone, follow structural trends, whatever may have been the drainage pattern before they were developed. They might have been "derived from" a system of southwestwardly flowing Permian consequents, or they might equally well have extended themselves at the expense of any other drainage pattern, and their development might have occurred at any time from Permian to Pliocene. Mackin did not take issue with Ruedemann as to the date of origin of these streams. He states:

> "The structural relations of the southwest flowing headwaters of the Susquehanna and of the East and West Branches of the Delaware are non-committal as to the genesis of these segments, which flow parallel with the folds, in weak rock belts that are, in part at least, anticlinal. They are clearly subsequents, but whether they are of the same generation of subsequents as the great majority of the post-Cretaceous streams of eastern Pennsylvania, or whether they represent parts of an older drainage system on higher land never covered by the Cretaceous sea, must remain an interesting speculation."[28]

The formidable objection to the theory of preserved Permian consequent drainage in the Delaware-Susquehanna region is the fact that the Susquehanna, in the 36 mile stretch between Pittston and Sunbury (P and S, Fig. 1), flows directly against the pitch of folded structures that are, according to the theory, supposed to have controlled the course of the stream. This specific relation of a major fold to a major stream can hardly be disregarded; if the southwest pitch of the Catskill strata caused the Permian drainage of the Catskills to flow southwest, the northeast pitch of the Pittston-Sunbury folds should have caused the Pittston-Sunbury drainage to flow northeast, and the present drainage, if inherited from Permian consequents, should flow in the same direction. This consideration, stressed by Mackin, is not mentioned by Meyerhoff and Olmsted in their restatement of the Ruedemann view. Mention, elsewhere in their paper, of a "natural movement of intermontane streams toward an orogenic depression in the vicinity of Harrisburg,"[29] fails as an explanation of the anomaly, first, because it is not clear how the "natural shifting" was accomplished, and second, because, as will be shown below, there is no evidence of an orogenic depression in the vicinity of Harrisburg.

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[28] Mackin: op. cit., p. 324.

No other specific longitudinal streams are mentioned by Meyerhoff and Olmsted. Statistical analysis of trends of streams in the Pennsylvania Appalachians fails to show any correlation between direction of flow of longitudinal streams and direction of pitch of related structures. This is interpreted as meaning that there is no genetic relation between direction of stream flow and structural pitch. The longitudinal streams appear to be, not Permian consequents, but subsequents controlled by weak rock belts.

Relations of transverse streams to structure. Meyerhoff and Olmsted discuss the specific structural relations of only one of the major transverse streams of eastern Pennsylvania, namely, the Susquehanna River. The Susquehanna serves well as a test case, for it is the largest stream of the area and, in its repeated crossings of ridges underlain by resistant Paleozoic quartzite, it epitomizes the problems of other southeast flowing drainage lines of the Northern Appalachians. They state:

> "In picking its way across the folds to the Piedmont, the Susquehanna plainly utilized and still approximately follows the deepest structural sag in the entire central Appalachian belt."[30]

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[29] Meyerhoff and Olmsted: op. cit., p. 33.
[30] Op. cit., p. 31.

The evidence for the presence of the sag supposed to have controlled the position of the stream is not explained. The folds crossed by the Susquehanna in the Ridge and Valley Province pitch to the northeast, from a major transverse upwarp in the fold mountain belt which lies some 40 miles southwest of the stream, to a major transverse downwarp which lies some 35 miles northeast of the stream (Figs. 1 and 2). Both of these structural elements are included by Keith on his structural map of Appalachian folds,[31] and both are clearly shown by the outcrop pattern on the United States and Pennsylvania geologic maps (Figs. 1 and 2). Pennsylvania owes its most extensive anthracite fields to preservation of the coal measures in "canoe shaped" synclines that lie along the transverse downwarp. The amplitude of the sag is indicated by the fact that these beds, which extend far below sea level in the coal fields, would, if projected southwest, be high above the present ridge tops near the Susquehanna Valley. It appears, therefore, that far from following a major transverse sag, the Susquehanna actually crosses pitching folds, well up on the flanks of a high upwarp in the folded belt. If even the most general relation existed between the initial surface expression of the folds, and structures at the present erosion level, the Susquehanna could not have taken its present course as a Permian consequent.

Second in order of size among the transverse streams of eastern Pennsylvania is the Delaware River. The segment of that stream between Deposit and Port Jervis (D and P J, Fig. 1) flows southeast, directly across the regional southwest dip from the Catskills that was stressed by Meyerhoff and Olmsted in a paragraph quoted above. If, as they state, the doming of the Catskills was sufficient to decant the Permian drainage of that country to the southwest, the southeast flowing Delaware cannot be considered a Permian consequent. Even if the warping was not so strong as they suppose, the position of the stream athwart the regional dip, and well up on the flanks of the Catskill dome, is fatal to the theory that its position was determined by the form of the Permian surface. Ruedemann's suggestion that the stretch of the Delaware in question is subsequent, although not accepted by the writer, is far more in keeping with structural relations, for the stream might have extended itself headward along an intercuesta lowland on the outcrop of relatively weak Catskill sandstones and shales when, at a higher level, the resistant conglomerates of the Pocono Plateau extended farther to the northeast.

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[31] Keith, Arthur: Outlines of Appalachian Structure, Geol. Soc. Am., Bull., Vol. 34, pp. 309-380, 1923.

It will be recalled that the initial postulate of the Meyerhoff-Olmsted theory was that the divide between northwest and southeast flowing streams of the Permian Appalachians was "northwest of Kittatinny Ridge, but not so far northwest as the edge of the Allegheny Plateau." But some of the major streams of the fold mountain belt head far back in the Plateau. The Pittston-Towanda (P and T, Fig. 1) segment of the Susquehanna, which falls in this group, is one of the most striking of the southeast trending drainage lines of the Pennsylvania region. Evidently this stream cannot be explained as a Permian consequent on the basis of the initial postulate as to the position of the divide.

It thus appears that the theory which would derive the present stream system of eastern Pennsylvania from a system of Permian consequents does not stand the test of critical analysis, for it fails to provide any consistent explanation for the directions of flow of longitudinal streams, or for the positions of transverse streams.

THE THEORY OF MODIFIED PERMIAN CONSEQUENT DRAINAGE.

A possible alternative view remains: that the southeast drainage of eastern Pennsylvania has evolved from a southeastwardly directed Permian system, with so complete modification by capture that few of the streams retain their initial consequent courses. It will be recognized at the outset that this view differs but little from the theory proposed by Davis. His major Permian "Anthracite River"[82] would have flowed southeast, rather than northwest as he supposed, and its direct descendent would be the Schuylkill River. The structural position of the Schuylkill permits this interpretation, for the stream lies near the transverse sag discussed in the last section. The lateral branches of the Anthracite-Schuylkill would have been trimmed off by the Delaware and Susquehanna Rivers, which would thus owe their positions to headward erosion and their present size to conquest. In so radically altered a drainage system there is no reason to expect that longitudinal streams should flow in the direction of pitch of related fold structures, for these streams would be largely subsequent. The principal test of the merits of the theory is whether the captures required in the development of the transverse streams are practicable.

[82] Davis: op. cit., pp. 451-453.

Johnson, in his presentation of the theory of regional superposition of Appalachian drainage from a Cretaceous coastal plain, has published a full analysis of this problem, and has shown that it is in the highest degree improbable that the major transverse streams, particularly the Susquehanna, could have gained their present courses by capture. Mackin, following Johnson, has stressed theoretical difficulties bearing on the possibility of headward growth of the Delaware River across such barriers as Kittatinny Mountain. The arguments set forth in these two papers have not been questioned, and need not be repeated here.

The single new line of evidence presented by Meyerhoff and Olmsted in this connection is the statement, quoted from Ashley,[83] that the water gaps of major transverse streams in the Ridge and Valley Province correspond, in position, with transverse zones of weakness in the ridge-forming strata. Their interpretation of the bearing of Ashley's observations on Johnson's theory of regional superposition must be examined briefly. They state that:

> ". . . to fit the facts (namely, the relations noted by Ashley, and other structural relations of streams that have been discussed elsewhere in this paper) into a theory of regional superposition from a coastal plain, one must attribute to the consequent drainage on the marine cover such an uncanny insight into the foibles of the buried structures that the theory becomes incredible."[84]

It is evident that this argument depends on the presence of a far higher degree of correlation between zones of weakness and stream courses than could be expected on the basis of chance; like the supposed correspondence between Triassic conglomerates and present streams, the problem is essentially statistical. The merits of the argument must be based, therefore, not only on the presence of zones of jointing and faulting at stream ways, but on the *relative absence of such structures between streams.* For if a given bed were generally faulted or fractured, or if zones of faulting and fracturing were closely spaced, the correspondence of a number of transverse valleys with fractured zones would have absolutely no bearing on the problem of whether or not the transverse streams were superposed from an uncomformable cover.

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[83] Ashley, G. H.: Studies in Appalachian Mountain sculpture, Geol. Soc. Am., Bull., Vol. 46, p. 1406, 1935.

[84] Op. cit., p. 32.

For every geologist who has studied the relatively inaccessible interstream stretches of Pennsylvania ridges, scores have examined roadside exposures in transverse stream valleys. Certain types of structural and stratigraphic work, which require transverse cuts, have been confined largely to the valleys. Furthermore, for every good exposure of structures on the heavily forested ridges between the watergaps, there are many in the gaps, where vigorous stream cutting and the works of man have combined to produce ideal conditions for geological observations. It appears, therefore, that the recognition of minor structural features in water gaps does not at all mean that such features are actually localized in the gaps. The apparent localization may be due wholly to the fact that these areas are more accessible, better exposed, and have been most carefully studied.

A further point may bear on relations of streams to minor structures. Gilbert and others have shown that certain joints in the Sierra granites are localized near stream valleys because of relief of internal stresses in the granites by the cutting of the valleys.[85] Whether such joints occur in the Pennsylvania quartzites is not known, although Johnson has noted exfoliation of the Pottsville quartzite-conglomerate which he attributes to relief from pressures superinduced by folding.[86] Certainly it would be well, in any survey of relations of streams to structures, to keep in mind the possibility that relief of stress due to cutting of transverse valleys might lead to the formation of joints.

Meyerhoff and Olmsted do not state whether these essential considerations were taken into account in their interpretation of the bearing of Ashley's observations on the theory of regional superposition. In the absence of such a statement the facts presented by them as to the degree of correlation between transverse zones of weakness and stream gaps certainly do not justify their conclusion that regional superposition of Appalachian streams is "incredible."

Space does not permit discussion of each of Ashley's cases; it may be stated in general that study of the Kittatinny gaps in the field generally bears out his observations as to the presence of minor faults and structural complexities, but leads to an interpretation which is diametrically opposed to the theory that the streams gained their transverse courses by capture controlled by these structural features. The channel of the Susquehanna, in the water gaps north of Harrisburg, is a most impressive example of very great and uniform rock resistance to stream cutting. It is nearly a mile wide, and is everywhere shallow; notably resistant beds in the Medina quartzite form lines of ledges, standing above the rushing waters, that can be followed with the eye from one bank to the other. Many of the resistant beds cause minor breaks in the longitudinal profile of the stream, and some can be traced up the steep valley sides to the ridge crest that stands from 500 to 700 feet above the valley floor. If the Susquehanna, which is the largest stream in eastern Pennsylvania, has difficulty in cutting downward to *maintain* its course across this quartzite barrier, it seems highly improbable that a small stream could have extended itself headward across the same barrier, at the same place. That the same small stream could have extended itself headward across three such barriers (as it must have done, according to the capture theory, in the five-mile stretch north of Harrisburg) is of a probability infinitely more remote (Fig. 2). The final, and, in the opinion of the writer, fatal objection to the capture theory is the fact that the small stream could have avoided the doubled outcrop of the Pocono quartzite by working headward in the weak rocks that encircle the synclinal nose of the Pocono. Scores of captures by subsequents working in such weak rock belts have been described in the Appalachians; not one case of capture across hard rock belts, in a situation comparable with that described above, has ever been found.

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[85] Gilbert, G. K.: Domes and dome structures of the high Sierra, Geol. Soc. Am., Bull., Vol. 15, pp. 29-36, 1904.

[86] Douglas Johnson: personal communication.

The same reasoning, and essentially the same conclusions, apply with greater or less force to every water gap in the Pennsylvania Appalachians. Difficulty of capture across one barrier is great; difficulty of capture by the same stream across two barriers is far greater; most of the larger transverse streams cross many barriers. Many of the crossings are unnecessary and wholly inexplicable if the streams gained their courses by selective headward erosion.

CONCLUSIONS.

The crux of the problem of evolution of Appalachian drainage lies in the explanation of the origin of the transverse streams. The major thesis of the Meyerhoff-Olmsted article is that these streams inherited their courses from southeastward flowing Permian consequents.

Too little is known about the conformation of the Permian surface in the Piedmont district to permit any definite judgment as to the degree of probability or improbability of their basic postulate that the Permian drainage of the Appalachian region as a whole was directed southeast; there is no tangible evidence that such was the case. The lack of correspondence between the positions of Triassic streams, as indicated by distribution of conglomerates near the western boundary faults of the Newark area, and the positions of present streams, is not fatal to the theory, for there is good reason to believe that Triassic streams may have shifted markedly, during some stages of sedimentation, on alluvial plains that extended west of the present western boundary of the Triassic Lowland. The theory of preserved Permian consequent drainage fails in part because it offers no satisfactory explanation for the greatly extended southeast courses of streams across highly variable structures; and in part because two of the three major transverse streams of the Ridge and Valley Province occupy courses that could not have been assumed by Permian consequents, *if there had been even the most general correspondence between the form of the Permian surface and structures at the present erosion.*

The italicized words above express the assumption on which any discussion of *consequent* drainage in the fold mountain belt must be based. If major Appalachian structures were not reflected in the Permian surface, the present master streams of the Atlantic slope might have inherited their courses from Permian streams which, for some unknown reason, happened to flow southeastward in the positions of the present streams. A postulate of this nature is not open to discussion. It is exactly equivalent to the statement that the present streams happened to assume their transverse courses for some unknown reason.

Generally accepted principles relating to causes and mechanism of stream capture in a folded mountain belt are based on study of many actual cases of capture in the Appalachians and in other similar regions. If our understanding of these principles is correct, it is in the highest degree improbable that such master streams as the Susquehanna could have gained their transverse courses by headward erosion.

The absence of any evident relationship between transverse streams and structure, and the parallel southeast trending courses of the streams, suggests that they were superposed. Various possibilities as to manner of superposition: as (1) from an overthrust sheet, or (2) from a weathered soil mantle, immediately present themselves. Analysis demonstrates that they are, for the most part, either inherently improbable (1, above) or wholly inadequate (2, above). Marine Cretaceous strata underlie the Atlantic coastal plain. Since these strata form a cuesta at its inner margin, it is certain that they formerly extended farther inland. In view of the fact that Cretaceous seas submerged a very large percentage of continental areas, over the earth as a whole, it seems probable that they may have extended some considerable distance inland across beveled Appalachian structures, and that the problematic southeast flowing streams may have been formed on the Cretaceous sedimentary cover when the seas withdrew.

The theory of regional superposition of Appalachian drainage, developed by Johnson on the basis of this postulate, provides a complete and simple explanation of the courses of the transverse streams, and for other long recognized problems of Appalachian geomorphology. Deduction of the consequences of the theory has led to the discovery of past changes, as in the Hudson-Watchung area, not known at the time the theory was formulated.[87] The logical character of the sequence of modifications by which Johnson derives the present drainage pattern of the Northern Appalachians from the southeastward flowing consequents of the Cretaceous mantle has not been questioned.

Johnson presented his view as a "working hypothesis," to be tested, in use, by other workers. The two points in the Meyerhoff-Olmsted article which bear directly on Johnson's theory, and might be considered tests, are the supposed correlation in position of Triassic and present streams, and the supposed correspondence of zones of weakness in Appalachian ridge-formers with stream gaps. The writer has endeavored to set forth evidence bearing on these points that is not included in Meyerhoff and Olmsted's statements. Whatever the judgment of the reader on these specific points, the many and serious difficulties faced by the alternative theory (or theories) proposed by Meyerhoff and Olmsted seem to strengthen the claim of the theory of regional superposition to careful consideration by students of Appalachian history.

[87] Johnson, Douglas: op. cit., pp. 103-130.

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The text of this article has been read by Professors Douglas Johnson and H. A. Meyerhoff, and has benefited by their criticisms and suggestions.

THE SEDIMENTATIONAL EFFECTS OF THE WORK OF MARINE SCAVENGERS.

E. C. DAPPLES.

ABSTRACT.

Data are presented describing the effect of crustaceans, echinoderms, worms, mollusks, fish and bacteria upon the sediments of the ocean floor. It is shown that these forms constantly ingest such quantities of bottom materials that benthonic life may be considered a very active agent in diagenesis. The feeding habits of the above animals are discussed with quantitative data upon the amount of inorganic material passed through the organisms. Coprolitic material is considered important in fine-grained sediments, and it is suggested that some oolites may be fecal matter. Fossiliferous strata are believed to be due to sudden annihilation or rapid burial of benthonic life, whereas many unfossiliferous beds are thought to have been deposited under optimum conditions for animal life.

INTRODUCTION.

Studies of aqueous sediments in the process of deposition indicate that benthonic life has influenced the nature of such material to a considerable extent. Attention to this observation was drawn some years ago by students of oceanography, who recognized that scavenging life could produce changes of color and structure in sediments, as well as a decrease in the size of the grain. The extent to which such alteration may take place is manifestly dependent upon the number of benthonic forms living within an area, and the rapidity with which the effects of ingestion are impressed upon the sediments. To interpret properly the environment under which aqueous sediments were deposited the influence of organisms must be considered. Many quantitative data showing the rapidity and degree to which organisms can effect a sediment are widely dispersed and the subject has thus escaped the attention it deserves. The writer considers, therefore, that a summary and correlation of the data, gathered entirely by others, is justifiable, to concentrate attention upon the geologic influences on sediments prior to their lithification.

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HABITS OF BENTHONIC LIFE.

Benthonic life, in considerable part, is composed of scavengers which are not distributed at random over the ocean bottom but are adjusted to the number of non-scavenging forms of life locally present. Thus, where other organisms are numerous, scavengers are likewise abundant; where scanty, scavengers are correspondingly reduced in number. Not only are scavengers adapted in number and kind to the food supply, but like other living forms, they are likely to be extremely sensitive to modifications of environment such as changes in turbidity, salinity, oxygen content, and temperature of the waters.

Benthonic organisms fall largely into two groups, those which are scavengers and those which, though not actual scavengers, rework the sediments because of their mode of life. The first group is composed of crustaceans, sea urchins, holothurians, worms and certain forms of bacteria. All of these eat the bottom to obtain the comminuted organic matter therein contained. The second class consists of fish, mollusks, and crustaceans, which burrow in the mud for protection or for the live food which is present.

THE WORK OF CRUSTACEANS.

Crustacea are widely distributed over the ocean floor and are found in deep as well as shallow waters. Copepods, whose diet consists largely of diatoms and other microscopic organisms, are noteworthy scavengers. Excrements of these organisms are minute sausage-shaped lumps which are taken in considerable numbers in nets and dredges along the bottom (1, 719). These castings contain the tests of coccolithophoridae and diatoms, many of which are well preserved. In the Norwegian Sea, copepods are present in enormous quantities just below colonies of diatoms, and they appear to feed entirely upon the dead diatoms which sink to the lower waters. A like habit has been observed by Murray and Hjort to be true of other organisms as well. They report that Sir John Murray "found that many deep sea animals—the hydroids, for example—had developed special apparatus for catching the minute shells and particles of food that fall from the surface waters" (1, 426).

The crabs of the shallow waters occupy cavities in rocks, shells, timbers, holes burrowed by the tube worms, and other like depressions which provide protection. They are extremely voracious animals, feeding on live or decayed flesh, and some devour large quantities of sand, mud, and shells to obtain any organic matter which may be present. Herrick (2, 185) has observed fragments of shells, coarse sand, and granules the size of duck shot in the intestinal tract of lobsters. Such occurrences were particularly common in small lobsters with fragile skeletons whose stomachs were literally crammed with water-worn shell fragments. Debris of this character must have had its attached organic matter entirely removed by wave action, prior to its ingestion by the lobster. This observation has led Herrick to suggest that much of the calcareous material, not regurgitated by the organism, is dissolved to furnish calcium carbonate for the shell. The larger crustaceans burrow to a considerable degree in the sediments below the immediate surface of the bottom.

Despite the large number of crustaceans which inhabit the seas their remains are rarely dredged from the ocean bottom. This may be the result of the porous and jointed character of the exo-skeleton which allows rapid disintegration, but it is also doubtless partially due to the action of other scavengers which rapidly consume the soft parts for food and the hard parts for their content of phosphorus.

THE WORK OF ECHINODERMS.

Sea urchins and holothurians occur in great numbers along most shore lines and coral reefs and even to depths of 6,000 meters. They are extremely sensitive to changes in salinity and therefore do not frequent areas of brackish waters. They are found most plentifully on bottoms, largely composed of sand or mud. Sea weed is one of the chief forms of food of the sea urchin, to obtain which it devours the entire material of the bottom upon which it lives. Its excreta consist largely of rounded sand grains (3, 50-52). On tidal flats where sea urchins are abundant, the bottom is frequently covered with their castings. In the Bermudas 80 to 90 per cent of the sand is made up of ground shell matter that has passed through the intestinal tracts of large sea urchins and holothurians. Verrill (4, 330) states that "the grinding up of the shells about the Bermudas was accomplished in the intestines of a large species of sea urchin (*Toxopneustea*) and two species of holothurians." Although corals add some 840,000 pounds of limestone annually to the Samoan reefs, about four times this amount is removed during the same period by sea cucumbers, coral eating animals and current action (5, 165).

Holothurians feed by placing their sticky tentacles into the sand and then transferring the particles to their mouths. Some large forms, such as *Stichopus,* are found in great profusion to depths of eight fathoms in littoral waters of islands in the warm seas. The intestinal tract of these animals usually contains considerable amounts of sand and the bottom is thickly strewn with their castings. Data gathered by Crozier (6) on the relation of the size of the *Stichopus* to the amount of sand contained in the intestinal cavity are given in Table 1.

TABLE 1.

Comparison of the length of *Stichopus* to the weight of sand contained in the gut.

Length of Stichopus, cms.	Length of gut, cms.	Weight of intestinal content (dry), grams.
10	50	5
12	60	9
15	70	14
17	80	19
26	115	48
27	125	52
30	130	63

This animal feeds peculiarly in that it fills its internal cavity completely and then does not resume feeding until it has emptied its gut through defecation. If the animal fed only once in 24 hours, 1.4 kilograms (dry weight) of sand would pass through it each month. Since feeding actually seems to take place about three times daily the amount of material increases to 4.2 kilograms per month. This does not mean that 4.2 kilograms of fresh sediment are eaten monthly, for much of the material has doubtless been previously reworked, perhaps repeatedly. Each time, however, the ingested matter is probably reduced to smaller dimensions and corroded by the intestinal juices. Crozier conducted further studies on more restricted areas and obtained the results shown in Table 2.

TABLE 2.

Weight of material eaten by *Stichopus* in a measured area.

Area in sq. ft.	Number of *Stichopus*	Kilos eaten per day	Gms. (dry) of sediment eaten per day per sq. meter of bottom
35,000	97	7.5	2.4
2,500	37	6.5	28
5,000	675	13.5	29
3,750	67	2.9	8
1,500	63	5.0	25

In an area covering 1.7 square miles on Harrington Sound on the coast of Bermuda between 500 and 1,000 tons of material pass through the intestinal tracts of these organisms each year. The castings rapidly disintegrate and after a few hours cannot be recognized as such.

THE WORK OF WORMS.

Worms form important scavengers, and are most effective in shallow waters where they are necessarily restricted to sandy or muddy bottoms. They prefer areas where large quantities of fixed algae supply abundant detrital organic materials upon which the worm may feed. Under optimum conditions they thrive in great numbers. Thus, along the shores of Holy Island the number of castings of lug worms (*Arenicola*) was estimated to range from 39,935 to 203,272 per acre and to average 82,000 per acre of sea floor, or 50,000,000 per square mile (7). Such a large number of individuals will pass tons of material through their bodies each year as shown in Table 3.

TABLE 3.

Weight of excremental material deposited on the surface of the sea floor by lug worms (based on Davison's data).

Sample	Location	Area meas. in sq. in.	Number castings in meas. area, carried up during 1 high tide	Number castings per acre	Wt. of single casting in oz.	Tons of castings deposited annually per acre	Thickness of sand deposited annually, inches
1.	Holy Island	13,534	87	40,322	1.5	901	5.93
2.	Holy Island	6,324	53	52,568	3	3,146	22.26
3.	Holy Island	7,844	88	70,372	2.25	3,147	20.82
4.	Holy Island	5,304	38	44,941	0.5	449	3.04
5.	Caves Haven	12,568	173	86,344	0.25	396	2.66
6.	Caves Haven	13,154	158	73,345	0.22	329	2.26

Davison (7) estimates that an average of 1,911 tons and a maximum of 3,147 tons of material may be eaten by these organisms per year over each acre of ground. The magnitude of these figures becomes significant when they are compared with one-half to 30 tons which is eaten per acre per year by *Stichopus*, an estimate based on Crozier's data. Such worms are known to burrow from one to two feet vertically in the sediments of the sea bottom, and Davison (7, 492) estimates that at Holy Island the entire bottom to a depth of two feet passes through their bodies during an interval of 22 months.

Peebles and Fox (8, 209) state that the fecal strands of the worm *Dendrostoma zostericola* "are composed of sand grains, particles of shell, and other inorganic matter held together by some kind of gelatinous matrix which seems also to be inorganic, possibly silicious in nature. The strands are not broken down by boiling water, or by nitric acid, but slowly by hot dilute alkali. Heating a mass of these strands in a crucible produces no charring such as would be expected if organic matter were present." The same species, when placed in tanks lacking organic constituents, burrowed into the sand but failed to pass any of the sediment through the alimentary canal. When organic debris was added, however, individuals soon began to ingest the sand.

Sipunculus nudus, a worm from the Bay of Naples, was found by Shipley (9, 422) to contain sand equal to as much as 52 per cent of the total weight of the individual (see Table 4). Such a high content of inorganic debris appears characteristic, for Shipley states that the alimentary canal is usually full of sand. Some particles of the sand are imbedded in the body wall and serve as stationary grinding agents which round the edges of other particles as they pass through the organism.

Table 4.

Sand contained in specimens of Sipunculus nudus from Bay of Naples.

Number of specimens	Weight of spec. grams	Weight of sand removed. grams	c.c. of sand removed
Aver. of 5 spec.	19.08	10.03	4 (approx.)
1		15 (approx.)	6
1		18 (approx.)	7
1		17 (approx.)	6.5
1		19 (approx.)	7.5
1		19 (approx.)	7.5

THE WORK OF ROCK-BORING FORMS.

Rock borers are found among all the principal invertebrates and include crustaceans, mollusks, sea urchins, worms and sponges. Verrill (10, 450) states:

> " . . . accumulations of shells would soon become far more extensive if they were not attacked by boring sponges and annelids. Certain common sponges belonging to the genus *Cliona* very rapidly perforate the hardest shells, in every direction, making

> irregular galleries and finally utterly destroying them. In the shallowest waters the most destructive species is *C. sulphurea* (Desor) which burrows in shells and limestone when young . . . "

Among the pelecypods all true rock borers select the rocks into which they enter, attacking limestone, shale, and sandstone readily but usually avoiding the denser and more resistant rocks such as conglomerates, igneous and metamorphic rocks. Jehu (11) reports that *Pholus crispata* prefers to bore into soft chalk but is capable of drilling into flint pebbles, especially where the flint is somewhat decomposed.

The most common of the rock borers is the mollusk *Saxicava* which is abundant in clear waters, both shallow and deep. It is found chiefly on limestones into which it bores readily by means of rotation of its delicate shell. Apparently the drilling is purely mechanical as no glands for the production of acids have been discovered in either *Saxicava* or *Pholas*, but it is possible that the soft parts of the body, which project beyond the shell, may secrete some form of solvent (5, 148). There are, however, some mollusks, namely the Date mussel (*Lithophagus lithophagus*) and some species of *Mytilus*, which burrow largely by means of an acidic solvent. The shells of organisms of this type are protected from solution by a horny, acid-resisting cover. The mollusk *Teredo*, commonly known as the "shipworm," is plentiful wherever sandy bottoms are found (12).

The effect of rock borers in aiding coastal erosion is emphasized by Jehu (11, 3) who quotes from Reid as follows:

> ". . . at extreme low water *Pholas* is very active in drilling its auger-holes into the chalk, and from the lower depths lumps of chalk brought up attached to seaweeds or by the dredge are honeycombed by *Saxicava* or annelids. This means that where living *Pholades* are crowded together on the chalk foreshore, each generation of the mollusk cuts a series of auger-holes from two to four inches deep, so weakening the intermediate parts that they are easily destroyed when *Pholas* dies. The length of life of this genus is unknown; but judging from the various sizes of shells found together, I doubt whether it is more than three years."

Jehu adds that *Pholas* is lowering the chalk floor at rates ranging from 0.7 to 1.3 inches annually but probably averaging about 0.5 inches.

Vaillant (14, 43) has observed that the annelid *Leucodore* burrows to depths of an inch or more, and estimates that in some localities there are 250,000 to 300,000 such borings per square meter. To a slight extent both limestone and coral are bored into by barnacles, but the only crustacean which actively burrows is a species of *Sphaeroma* which drills in wood, soft sandstone, or shale. It is especially active off the New Zealand coast where it is known to be very effective in erosion of shale (5, 150).

THE WORK OF FISH.

Most fish are not true scavengers. Yet the voracious habits of many result in the consumption of considerable quantities of dead organic matter. This is especially true of those forms which plow into the bottom in search of food. Along the Dogger Bank at depths of 38 fathoms numerous whitings and flounders have been caught whose stomachs contained large amounts of sand and small crustaceans. These fish bury themselves in soft bottom muds or sands, sometimes to depths of several inches and work over the bottom in search of food. Verrill (10, 449) has observed that many fish like the hake (*Phycis*) root in the muddy bottom with their snouts, while other fish, such as *Macrurus*, burrow with their sharp tails. In the Red Sea, and other regions suitable to coral reef formation, the fish *Pseudoscarus* lives on the live coral. By biting off large quantities of rock, these fish aid materially in the destruction of the reef (5, 166).

Considering the enormous quantities of fish in the sea it may appear surprising that their remains are so rarely found. It should be realized, however, that their corpses are rapidly attacked by all forms of scavengers, and that the soft parts quickly decompose and disintegrate while the fragile skeletons are readily broken and scattered on the bottom. Apparently the only vertebrate remains found in dredging are teeth and ear-bones. On only four occasions did the Challenger expedition, dredging at moderate depths, bring bones to the surface. However, in the great abysses, the region of the red clays, whale ear-bones are commonly found. Apparently phosphatic material such as bone can withstand the solvent action of water for only a short time, and, moreover, much of this phosphatic matter is greedily eaten by scavengers.

BACTERIA AS SCAVENGERS.

Bacteria break down organic matter to its ultimate complete elimination. Speaking broadly, bacteria do not seem to be more abundant near the shore than in deeper waters. This is illustrated in Table 6 (15, 486). In summarizing his findings,

TABLE 6.

Abundance of bacteria in sea water, and in sea bottom deposits south of Martha's Vineyard, July, 19-20, 1931.

Depth of water in meters	Distance from land in miles	Number of bacteria per c.c. water or per gram of dry mud			
		Surface water	Bottom water	Top 2.5 cm. mud	Mud at 10 cm. depth
18	1.5	65	159	....	....
38	12	183	1900	238	....
55	23	185	....	1050	....
94	55	735	....	7700	2700
163	72	27	....	1000	....
345	77	480	....	1400	460
570	81	190	....	1280	900

Reuszer (15, 495) states:

> "Bacteria in the bottom deposits were much more numerous than in the overlying water. Muds contained many more bacteria than did sands. The number of bacteria decreased with depth into the mud, the most marked decrease being in the first 2.5 centimeters. . . There appeared to be on the surface of the mud a very thin layer containing organic matter in a less advanced stage of decomposition, supporting a bacterial growth much richer, not only in numbers but also in the types of bacteria than in the lower layers. The vertical distribution of bacteria in the mud was not related to the carbon content, since the amount of carbon sometimes increased with depth, while the number of bacteria always decreased with depth."

COPROLITIC SEDIMENTS.

One cannot escape the conclusion that tremendous quantities of mud and sand, comprised in the immediate surface of the bottom, passes through the intestinal tracts of organisms. Such material is necessarily ground down to finer dimensions, subjected to solution, and may be slightly cemented, through admixture of digestive remains. It may be transported to other portions of the sea floor. Thus that portion which is eaten by the nekton may be transported some distance before it is ejected. In this manner much of that material which the existing currents were incompetent to move, is reduced in size by grinding and solution within the body of the organism. As a result, many of the particles are now of transportable sizes, and this debris may be moved elsewhere.

Commonly such sediment, representing biotical reworking, may be recognized in the form of small ellipsoidal fecal pellets. Because they disintegrate rapidly on compaction, such pellets generally cannot be recognized below the immediate surface of a bottom which may be literally covered with coprolitic matter. Instances have been observed by Moore (16, 358) in the Clyde Sea, where in some places the entire bottom consisted of fecal matter; indeed he regards it as normal for such pellets to compose up to 40 per cent of the whole sediment. They average as many as 3,400 per square inch of sand. Murray and Hjort (1, 148) cite the excreta of various benthos as being so abundant in the Atlantic that they propose the term "coprolitic muds" for the deposits. Although the present knowledge suggests that these pellets are all poorly cemented and disintegrate upon compaction, it is possible that under some conditions they may be preserved. The fecal pellets are cemented to some degree when ejected, and it is impossible that this would aid in preservation. Structures of this type in a rock would suggest oolitic texture. Behre* has suggested the possibility of such an explanation for the peculiar "fucoid" markings found in the Tyrone and Birdseye formations of Kentucky and Indiana, and in the calcareous beds of the Spechts Ferry member of the Platteville formation in Wisconsin. Some of the peculiarly mottled beds in the Galena dolomite may represent the markings of worm coprolites.

SCAVENGERS AND ROCK CHARACTER.

In view of the facts cited, the preservation of organic remains in the rocks of the geologic column should be even more unusual than has been generally supposed. In areas where life is abundant and deposition slow, scavengers should destroy all traces of organic remains. Is it not possible that the unfossiliferous portions of our finer-grained marine sediments represent deposits which have accumulated under such conditions? Where sedimentation is rapid, the tests of animals may be preserved if the scavenging animals are unable to keep the bottom cleaned of organic debris before it is buried. Only the surface mud appears to be reworked and the material buried to depths of a few inches should be safe for preservation. Likewise, the continual burrowing in the surface muds and sands must surely destroy stratification. Twenhofel (17, 109) has found this to be true in the case of Lake Monona, Wisconsin, where the black muds of the bottom are populated with life which has destroyed all evidences of stratification and organisms.

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* Personal communication.

On those ocean bottoms over which the waters are toxic, benthonic life is lacking, and hence the remains of plankton and nekton can collect on the bottom, and the resulting beds become fossiliferous. Sudden catastrophes may cause wholesale destruction of sea life; the bottom dwellers are likewise destroyed and hence the chances for the preservation of fossils in the sediments increases (18, 19, 20). Thin shale layers within limestones are commonly fossiliferous. They indicate a change in sedimentary conditions. Do they perhaps point to the abrupt inauguration of rapid sedimentation, with consequent sudden destruction and burial of life?

In the light of the data presented, in those areas where sedimentation is slow and the waters can support a highly populated sea bottom, the bottom sediments will be eaten and re-eaten. Their content in organic debris will decrease in coarseness with each passage through the scavenger. The resulting rock might be a lithographic limestone, a massive fine-grained sandstone, or a dense shale, totally devoid of fossils.

It would thus appear that explanation of unfossiliferous rocks as deposits made under conditions adverse to life is not necessarily true. Conversely those beds which are highly fossiliferous may represent conditions of widespread destruction of animal life, or regions where toxic products formed great death traps, fatal not only to the larger inhabitants but to the potential scavengers as well.

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AGE OF THE SELKIRK AND ROCKY MOUNTAIN UPLIFTS IN CANADA.

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ABSTRACT.

The exact dating of the Selkirk and Rocky Mountain uplifts in Canada is discussed in this paper and evidence is submitted to demonstrate that the uplift of the Selkirks took place in Cretaceous time whereas the Rocky Mountain uplift was in post-Paleocene time.

INTRODUCTION.

It has long been known that the Rocky Mountain uplift in western North America is of a two-fold nature,—an earlier disturbance at the end of Cretaceous time which drove the remnants of the Cretaceous sea from the interior of the continent and a later movement at the end of Paleocene time when further folding and uplift took place. So far as the Canadian Rockies are concerned there has never been any serious attempt to correlate the uplift of the mountains along the western flank of Alberta with either of these two disturbances. A hasty scanning of the literature would justify the assumption that the general opinion held by geologists would place the uplift of the Canadian Rockies at the end of Cretaceous time rather than at a later period. As a matter of fact there is very little opinion expressed on the subject, largely, presumably, on account of lack of definite evidence. The front ranges and foothills in Alberta differ markedly from those farther south in the total lack of igneous intrusions which would be of great assistance in placing the exact time of the uplift. It is also notable that the later Cretaceous beds (and early Tertiary if any) are not exposed within the mountains behind the front ranges, probably due to the erosion of these beds since the mountain uplift or to their loss through faulting during the uplift. Such a loss of evidence greatly mitigates against any attempt to fix the time of the main disturbance with any degree of exactitude. There is, however, a certain amount of evidence in the foothills regions which may be used within certain limits and it is pertinent at this time to review such evidence as pertains to the time of the Rocky Mountain and Selkirk uplifts so far as it applies to the Canadian region.

THE FOOTHILLS SEQUENCE.

A proper understanding of the evidence to be submitted necessitates a knowledge of the stratigraphy of the Cretaceous and early Tertiary sediments of the foothills region. These sediments will be first discussed and later the evidence will be deduced from them as to the major time of disturbance. The following table summarizes the Cretaceous and early Tertiary sediments in the foothills.

Table of Cretaceous and Early Tertiary Sediments in the Foothills.

Periods	European Ages	Formation	Thickness	Lithology
Paleocene		Paskapoo	500 ft. ±	Sandstone & shale
	Senonian	Edmonton	1500 ft. ±	Sandstone & shale.
		Bearpaw	200 ft. ±	Shale
		Belly River	2500 ft. ±	Sandstone & shale
Cretaceous	Emscherian Turonian Cenomanian	Colorado (Alberta)	2500 ft. ±	Mostly shale
	Albian Aptian	Blairmore	2000 ft. ±	Sandstone & shale
	Barremian	Kootenay	300 ft. ±	Sandstone & shale with coal

The Kootenay formation is the lowest formation in the Cretaceous and lies directly on the Jurassic Fernie shale. It consists of sandstones and shales with coal seams and the contained flora shows the age to be Barremian. There must be a considerable break in time between the Kootenay and the underlying Fernie though field evidence of such a break is largely lacking. The Kootenay, in common with the other Cretaceous formations in the foothills thickens towards the west.

The Blairmore formation resembles the Kootenay in many respects. It is usually a little coarser and the sandstones are more of a greenish colour. A strong conglomerate bed lies at the base of the Blairmore and in the westerly exposures other conglomerate beds occur higher in the formation. The thickening of the formation toward the west is quite pronounced.

The Blairmore is continental in origin and the contained flora demonstrates an Aptian-Albian age for most of the formation.

The Colorado, or Alberta, shale represents a marine invasion in Upper Cretaceous time. The shales are dark grey to black in colour and very little sandstone is present throughout.

The Colorado shale is followed by another series of continental sandstones and shales comprising the Belly River formation. These beds are very similar in appearance to the Blairmore formation and the separation of the two formations on lithological evidence is attended by considerable difficulty. The Belly River contains some rather fine grained conglomerate beds at certain horizons.

In the southern foothills the Belly River formation is separated from the overlying Edmonton formation by a marine shale,—the Bearpaw formation. This formation is quite thin in the foothills and its extent is quite limited in a northern direction.

The Edmonton formation is of continental origin and bears a very strong resemblance to the Belly River. In the northern part of the foothills area where the Bearpaw shale is absent, the two formations cannot be separated with any degree of certainty.

The Paskapoo formation overlies the Edmonton disconformably. This disconformity has been observed both in the foothills and on the plains to the east. There is no sign of an angular unconformity at this horizon and it is very probable that the period of erosion which took place at this time was quite short. The Lance horizon has never been detected in the upper beds of the Edmonton and it is probable that they were either never deposited on account of regional uplift at that time or that they were eroded after the uplift and before the deposition of the Paskapoo.

The Paskapoo is continental in origin and closely resembles the underlying Edmonton formation. The Paleocene age of the formation is ascertained by fossil vertebrates, invertebrates and plants. The Paskapoo is the surface formation over a large part of Alberta and consequently has suffered considerable erosion. For this reason we know little about its original thickness.

THE EVIDENCE FOR THE TIME OF UPLIFT:

A study of the continental sediments of Cretaceous age exposed in the foothills shows quite definitely that the source of supply of sediments was from the west. If we consider the Kootenay-Blairmore group first we find that these formations thicken greatly as we trace them west and conglomerate beds become more frequent. It is fortunate that we find these formations exposed right across nearly to the westerly side of the Rockies in Elk River valley in Crowsnest pass. It is quite evident that the source of supply of the sediments must have been to the west of the Rockies as the Kootenay-Blairmore formations were infolded with earlier beds in the Rocky Mountain uplift. This source of supply could only have been the Selkirk mountains to the west of the Rockies which must have commenced their upheaval at this time, i.e., in the Lower Cretaceous. It is an excellent dating for the first uplift of that range and as the first coarse bed in the Lower Cretaceous sequence is the conglomerate at the base of the Blairmore, it is probable that this bed marks the beginning of the main uplift and that the time was the end of the Barremian or early Aptian.

Uplift ceased at the end of Blairmore time and the Colorado sea invaded the area. This sea must have extended right across to the foot of the Selkirks. We cannot trace the shales laid down in that sea across the Rockies but where we last see them in the front ranges they show no sign of near shore conditions and are 2,500 feet in thickness. It seems reasonable to suppose, therefore, that the sea covered the present Rocky Mountain area.

The Colorado sea was driven eastward by another uplift and another series of continental beds were deposited—the Belly River formation. This formation appears in the foothills and far out on the plains to the east, but cannot be followed far into the Rockies. The type of beds, however, is so similar in appearance in every respect to the Blairmore formation that there can be little doubt that the source of sediments was the same, i.e., the Selkirks. These beds are infolded in the foothills structure and must, in consequence, have been deposited before the uplift of the Rockies. The Belly River beds, therefore, represent a further uplift in the Selkirks.

This disturbance ceased for sufficient time to allow the

Bearpaw sea to invade the present outer foothills area in the southern part of the province. The invasion was of short duration. Another set of continental beds, the Edmonton, followed, in all respects similar to the previous ones. They were deposited before the Rocky Mountain uplift as they were deformed by it. They undoubtedly represent a further uplift in the Selkirks.

A disconformity separates the Edmonton from the overlying Paskapoo. As there is no angularity expressed at this break it is reasonable to assume that no mountain building movement took place in the vicinity of the foothills. This disconformity probably represents the reflection of strong crustal movements farther to the south where the Laramide revolution was commencing. The Paskapoo represents the same types of sediments as the Edmonton and the source of the sediments was probably the same. The Paskapoo is now known to be involved in the outer foothills structure[1] and was therefore deposited prior to the Rocky Mountain uplift in Alberta.

We have attempted to show in the preceding pages that the source of our coarse Cretaceous non-marine sediments was in the Selkirk Mountains which were being uplifted throughout Cretaceous time. We have also shown that Cretaceous sediments as well as the overlying Paskapoo formation were all greatly disturbed by the Rocky Mountain uplift and, therefore, that disturbance must have post-dated the Paskapoo formation of Paleocene time. It remains only to attempt to tie in as closely as possible the time of the disturbance during the Tertiary. Here, the evidence is more scanty but nevertheless sufficient for the purpose.

In central and eastern Alberta we find several elevations rising several hundred feet above the plains which represent residuals of erosion. They are composed of Cretaceous sediments overlain by Paleocene strata and capped by a heavy conglomerate bed. The age of the conglomerate has been proved by vertebrate fossils found in the Cypress hills to be Oligocene in age. The conglomerate is composed of coarse quartzite boulders and the source of these boulders is undoubtedly the Rocky Mountains; also the mountains must have been much higher than they are now to have produced a gradient sufficiently steep to have allowed these boulders to be carried down to their present position by stream action. No one has doubted the source of these boulders. It is arrived at by a process of elimination.

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[1] Hume, G. S.: Geol. Surv., Can., Map 277A, 1932.

In all cases where the conglomerate has been found in Alberta, the sequence is the same,—fine-grained Paleocene sediments derived from the Selkirk Mountains overlain by coarse conglomerates derived from the Rockies. The Rockies, therefore, were fully raised by Oligocene time and as we find no Eocene sediments whatsoever in Alberta it seems reasonable to assume that if the mountains were uplifted and being eroded during Eocene time some remnant of those sediments should be found. It seems more reasonable to postulate that Eocene time was largely a period of erosion, in Alberta without the mountains being uplifted, at least to any great extent and that the main uplift of the Rockies was at the beginning of Oligocene time and that the first debris derived from their erosion was swept down over the plains of Alberta, the remnants of which are still preserved on top of many of the residual hills.

University of Alberta,
Canada.

SCIENTIFIC INTELLIGENCE.

GEOLOGY.

The Quaternary Ice Age; by W. B. WRIGHT. Pp. xxv, 478; 155 figs., 2nd edition, New York and London, 1937 (Macmillan and Co., 25s).—In this volume Mr. Wright has revised and brought more nearly up to date the work he published first in 1914. It still stands as the fullest discussion of the Pleistocene ice age in the English language. The improvements consist chiefly of the introduction of many new references to the literature, including the placing of a bibliography at the end of each chapter, and of new unit-discussions. Outstanding among the latter are treatments of the phenomena of deglaciation, and of the complicated relation between glaciation and the level of the sea. In addition there is a fuller discussion of the Pleistocene stratigraphic sequence in Britain, including the stream gravels of southern England, and the problem of the interglacials is much more fully considered; its treatment was defective in the earlier edition.

The chapter on Quaternary mammals (exclusive of man) remains essentially unchanged, but the terminology of the human cultures has been modernized. As in the earlier edition, however, only the genus *Homo* is considered; hominid fossils of pre-Neanderthal date are not treated.

Mr. Wright is, of course, more at home in the European Pleistocene than in the American. The latter is much the less fully set forth, and appears not to have been modernized to the same extent as the discussion of features across the Atlantic. Thus the Cordilleran "ice sheet" is still stated to have been a center of ice dispersion, the outer limit of the Wisconsin drift is still referred to as "the great Kettle Moraine of the United States," and the Iowan drift is retained as a major stratigraphic unit in the Mississippi basin section.

No doubt few discussions of the causes of the exceptional Quaternary climates can avoid being tainted to some degree with the predilections of their authors; and for this reason one ought not to judge Mr. Wright too severely for the somewhat less than equal treatment that he accords to the hypotheses thus far advanced to explain this absolutely unsolved problem. In connection with the hypothesis of variable solar radiation he mentions Dubois and Simpson but not Huntington, nor does he consider the important implications of Simpson's form of this hypothesis. He discusses the elevation (topographic) hypothesis summarily, and in this connection makes no mention of the important contributions made by Brooks. He devotes major consideration to the "astronomic theory" as set forth by Croll and later by Köppen and by Soergel, and accepts (rather naïvely, it may seem to some readers) the notion of great displacement of the Earth's axis relative to the continental masses, in the geologic past.

In spite of these criticisms, the book is a distinct improvement over its earlier form, and will doubtless continue to serve as a very useful reference work on the Pleistocene glaciation.

RICHARD FOSTER FLINT.

A Descriptive Petrography of the Igneous Rocks. Vol. IV. Pt. I: The Feldspathoid Rocks. Pt. II: The Peridotites and Perknites; by ALBERT JOHANNSEN. Pp. xvii, 523; 181 illustrations. Chicago, 1938 (The Chicago University Press, $4.50).—The present volume is the final and concluding installment of Professor Johannsen's great treatise on Petrography, the first volume of which appeared in 1931. A distinguishing feature of this work, as is well known, is the emphasis on quantitative data, and in the four volumes are assembled practically all the rock analyses from the world's literature in which chemical analysis and mineral composition have been determined on the same specimen. For this great service Professor Johannsen has placed petrologists under a heavy debt of gratitude.

An extraordinary number of newly coined rock names appear in the present volume, many of them coined by Professor Johannsen to designate rocks that fit into previously unnamed compartments of his classification. In the foreword to the present volume Professor Johannsen has found it necessary to explain again that he has included the names of all rocks whose positions could be determined, regardless of whether a name duplicates an older one or whether or not it is desirable. This procedure is inevitable in a work that professes to be complete as a reference source. The cumulative effect of the enormous array of rock names thus brought together—euphonious, cacophonous, and otherwise, drawn from every language civilized and uncivilized, is nothing short of appalling. The names are devoid of system, connotation, or mnemonic association. Some authorities, it is true, have pointed out that the number of rock names is much fewer than the number of names in other sciences, for example, botany, but this defense or palliation of the present method is hardly convincing. A better way to solve some of the difficulties of the problem of nomenclature would seem to be, as has often been suggested before, somewhat along the lines adopted by chemistry, by building a logical system in which varieties are indicated by appropriate adjectival qualifiers. The realization of this hope appears remote at present. Meanwhile, we rejoice that Professor Johannsen has brought to a successful conclusion so immense a piece of work as the Petrography.

ADOLPH KNOPF.

PALEONTOLOGY.

The Dentition of Sinanthropus pekinensis: a Comparative Odontography of the Hominids; by FRANZ WEIDENREICH. 2 vols.; pp. v, 180; 36 pls., 345 figs., 49 diagrams (comprising vol. 2). Palaeontologica Sinica; N. S. D. 1, W. S. 101. Peking, 1937.—In this monumental study, based on 147 juvenile, adolescent, and adult teeth representing approximately 36 individuals of both sexes, Doctor Weidenreich has presented far-reaching interpretations based on all the known data concerning the dentition of Peking Man. Having been oriented by the introductory pages, the reader progresses from a comparative description of individual teeth, through sections on the eruption, size and proportion, sexual differences, relationship to jaws, comparison with controversial forms, specific characteristics, course of evolution, and pathology. The author is exceptionally thorough, leaving only a few queries unanswered in the reader's mind. The terminology is well chosen. There are numerous comparisons with infra-hominid anthropoids, but apparently the author did not have access to a number of the fossil forms. The following represent some of the conclusions reached: The teeth are long-rooted, very large, and robust, compared to those of *Homo sapiens* and *H. neandertalensis*. A persistent cingulum is characteristic. Diastemata occur only in the deciduous dentition, mesially and distally placed with relation to the milk canine. The upper permanent canine is large and stout, and projects beyond the crown of P^3. The canines recall those of fossil *Pongo*. The strong P^3 tends to be two-rooted, with traces of a third branch; the mesial portion of the basal part of the buccal crown surface projects considerably. P^4 is a more advanced type. The P_3 shows the same root morphology as P^3. The molars are taurodont, and show a well-developed *Dryopithecus* pattern. The milk teeth are primitive, the canine erupting last. The second true molars follow the permanent incisors in eruption before the milk canine and molars are shed, as in the great apes. The teeth of *Homo*, as compared to *Sinanthropus* and the great apes, have been simplified by the loss of size, wrinkles, and the *Dryopithecus* pattern. In dental morphology, *Australopithecus* comes closer to *Sinanthropus* than does any other great ape. *Pithecanthropus* and *Eoanthropus* are genera based on a mixture of fragments of several types of men and apes. Changes in dentition reflect a general transformation, human dental evolution being but one phase of a manifold, integrated, orthogenetic process. "*Sinanthropus* must be considered as a stage leading directly to Recent man."

G. EDWARD LEWIS.

BOTANY.

Essays in Geobotany; edited by T. H. GOODSPEED. Pp. xxv, 319; frontispiece, 14 photographs, 25 figures in text. Berkeley, 1936 (University of California Press; $3.50).—Issued in honor of Professor William Albert Setchell, this volume comprises a series of eleven authoritative papers on various geographical aspects of the subject more familiarly known as plant ecology, together with a biographical sketch of Professor Setchell and a list of his published papers.

Titles, length and authors of papers are as follows: The rate of plant migration (7 pages) by O. W. Arrhenius; The origin of *Crepis* and related genera, with particular reference to distribution and chromosome relationships (45 pages) by E. B. Babcock; The succession and distribution of Cenozoic floras around the northern Pacific basin (31 pages) by Ralph W. Chaney; The origin of the desert climax and climate (53 pages) by Frederic E. Clements; The strand and dune flora of the Pacific coast of North America; a geographic study (46 pages) by William S. Cooper; The genetic phytogeography of the southwestern Pacific area, with particular reference to Australia (6 pages) by Ludwig Diels; The rôle of terrestrial algae in nature (23 pages) by F. E. Fritsch; The plant as a metabolic unit in the soil-plant system (27 pages) by D. R. Hoagland; Malaysian phytogeography in relation to the Polynesian flora (15 pages) by E. D. Merrill; Plant communities of the world (28 pages) by Eduard Rübel; Antarctic plants in Polynesia (20 pages) by Carl Skottsberg. G. E. NICHOLS.

Krakatau, 1883-1933; by W. M. DOCTERS VAN LEEUWEN. (Forms Vol. 46-47 of Ann. du Jard. Bot. de Buitenzorg). Pp. xii, 506; frontsp., 10 figs., 60 photographs on 36 plates, map. Leiden, 1936 (E. J. Brill, 35 guilders).—During the year 1883 occurred the catastrophic eruption of the volcano Krakatau, situated midway between Java and Sumatra and about 25 miles from the nearest point of each. This eruption resulted not only in the destruction of the luxuriant tropical vegetation which at that time covered much of the island of Krakatau and two neighboring smaller islands but also, presumably, in the complete obliteration here of all traces of plant and animal life of any description. The ensuing half-century has witnessed what is generally regarded as one of the most remarkable experiments of Nature within historic time, namely the gradual recolonization and reclamation by plant life of this barren and comparatively isolated tropical island. The opportunity thus afforded to study the sequence of plant invaders, their methods of migration and establishment, the development of a vegetation, and the formation and succession of plant communities has been taken advantage of by a considerable number of botanists whose published observations form an impressive list. Foremost among these should be mentioned the pioneer investigations of M. Treub and A. Ernst. Treub, at that time director of the world-famous Botanical Garden at Buitenzorg, Java, first visited Krakatau in 1886, three years after the eruption, and again in 1897, and his accounts did much to focus the attention of botanists on the unique interest of the "Krakatau experiment." But of especial importance in this respect was Ernst's book "The new flora of the volcanic island of Krakatau" (1908), the publication of which followed his visit to the island in 1906. Subsequently, and not to mention numerous lesser publications, have appeared C. A. Backer's book "The problem of Krakatau as seen by a botanist" (1929), Ernst's "Das biologische Krakatauproblem" (1934), and now this present volume.

Docters van Leeuwen, like Treub, was for many years director of the Buitenzorg Garden and his book has as its background a long series of first-hand studies during the period 1919-1932, when no less than a dozen separate excursions were made to the Krakatau group of islands. But the work is much more than a description and discussion of personal observations. The author's primary object has been to present a summary of all the more important botanical investigations which have been made on the island during the 50-year period following the eruption. Among other topics are discussed the eruption itself and its influence upon the original vegetation, the historical development of the new flora as recorded by various observers, the organization and succession of plant communities, and studies by various authors of the recolonization of comparable areas in other parts of the world. Nearly 200 pages are devoted to a graphic account of the present-day plants of the islands, exclusive of algae and fungi, with copious notes for the various individual species on the methods of transport by which they have reached the islands, the dates when first observed, local distribution, and other matters of ecological interest. This flora now comprises a known total of 33 mosses, 38 liverworts, 61 pteridophytes, 2 gymnosperms, 180 dicotyledons, and 81 monocotyledons.

Of particular importance is the author's discussion in regard to the controversial question as to the completeness with which organic life on the islands was destroyed as a result of the eruption. Treub, in 1886, was convinced that all life had been extinguished by the cataclysm; so also was Ernst, in 1906; while according to Backer (1909), as quoted by Docters van Leeuwen, "Nothing justifies the surmise that remnants of the old flora had remained." But a remarkable reversal of opinion was manifested by this last-named author in his 1929 book, written several years after severing his connection with the Buitenzorg Herbarium, where he had been stationed as Botanist for many years. Indeed Backer's principal motive in writing seems to have been to discredit the idea of a complete biological sterilization of the islands by the eruption. "After the scornful discussion of the results of all botanical investigations about Krakatau, which he designates as 'these wagon-loads of rubbish,'" to quote Docters van Leeuwen, "Backer ends his work, which is destructive and not constructive, with the following sentences: '(1) It is not at all proven that by the eruption of 1883 all the vegetable life on Krakatau was destroyed. (2) Even if this could be proved, we know—with the exception of the littoral flora—nothing at all about the manner in which the new vegetation has appeared. Only guesses without scientific value have been made, but no reliable observations nor experiments. (3) Therefore the Krakatau problem can neither now nor in the future either be posed or solved, and it is of no importance at all for Botanical Science.'" Backer's sweeping arraignment of widely accepted ideas affords ample justification for the amount of space which is devoted to this topic in the present volume. Unfortunately the question is one which can never be settled positively, either pro or con; but at any rate, after reading Docters van Leeuwen's authoritative critical analysis of the facts and arguments which Backer advances in support of his opinions, one is convinced that Backer certainly has proved little. On the contrary, one is fully disposed to agree with the present author when he concludes "that we are justified in assuming: that the original vegetation has been annihilated completely and that the plant-covering now present in the islands must therefore consist of immigrants." G. E. NICHOLS.

A Manual of Southern California Botany; by PHILIP A. MUNZ. Pp. xxxix, 642; 310 figures. Claremont, California, 1935 (Claremont Colleges, $5.00).—To one familiar with the large tracts of country covered by our standard eastern manuals, it seems surprising at first thought that southern California should merit a special manual of its own; and yet, while covering the flora of an area scarcely one-twentieth as large as that serviced by the eighth edition of Gray's Manual, the number of species included in this present volume is considerably more than half as large as that contained in its eastern progenitor: approximately 2,600 as compared with 4,000. Furthermore, probably no section of this country has so large a group of endemic plants as that centering in southern California.

In form, typography and general treatment of material this volume conforms closely with the time-proven practice of other recent manuals, with complete keys to and short comprehensive descriptions of all species, accompanied by ample illustrations. Of special interest to the general botanical reader, however, is the comprehensive account of the distribution of southern California plants which is presented in the introduction, including a description of the geological history and physiographic features of the region, its life zones and climatology, and the affinities and endemism of the native flora, followed by detailed lists of plants peculiar to or characteristic of the various physiographic regions.

G. E. NICHOLS.

An Illustrated Manual of Pacific Coast Trees; by HOWARD E. MCMINN and EVELYN MAINO. Second edition. Pp. xii, 409; 22 photographs, 393 figs., and 2 maps. Berkeley, 1937 (University of California Press; $3.50).—This book affords an admirable exposition of the possibilities of popularized scientific writing. While prepared primarily to meet the needs of the interested layman, this end has not been accomplished at the expense of scientific accuracy. The book is one which should satisfy scientist and layman alike.

Previous to its appearance no publication was available which covered both the native trees of this region and the introduced forms which are so widely planted in parks and gardens. The present volume takes into account both of these groups. It contains descriptions and keys for the identification of all the native trees, nearly 150 in number, and about 400 of the more important exotics. A majority of these are represented by either figures or photographs, the latter being employed only for the palms and related forms. The figures, all original, are well conceived and beautifully drawn; the descriptions are concise and to the point; the analytical keys are clearly constructed. The introduction, among other things, contains a section on how to use the manual which will be useful to the beginner, together with an instructive discussion as to the geographical origin and distribution of both native and introduced species. G. E. NICHOLS.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Mother earth: Being letters on soil addressed to R. G. Stapledon; by GILBERT WOODING ROBINSON. Pp. viii, 202; 1 pl., 7 figs. London, 1937 (Thomas Murby and Co., 5/6.).—The author set out to write, "a book in which the essential knowledge about soils is presented in clear perspective; a book that will give to workers in other fields, geologists, geographers, ecologists, agronomists, and Directors of Plant Breeding Stations, all they need to know for the benefit of their own studies."

Each of the seventeen chapters takes the form of an intimate letter addressed to "My dear Stapledon." The more important aspects of soils are treated in a clear and concise way. Soil materials and the development of typical profiles receive adequate consideration for an understanding of the facts of soil genesis and treatment of the physical and chemical properties is especially good. All who are interested in the soil as a natural body will profit by reading the letters entitled, "Soil Surveys," "Arable, grass, and forest," and "Waste lands."

The scientific attainments of the author are a sufficient guarantee for the technical accuracy of the work and the informal and direct writing makes reading easy. H. J. LUTZ.

OBITUARY NOTES.

DR. HERMANN AUGENER, of the Hamburg Museum, died on April 5 in his sixty-sixth year. Augener was a specialist on the marine annelids or Polychaeta and became a leading authority on the group.

DR. W. EAGLE CLARKE, honorary supervisor of the Bird Collection and formerly keeper of the Natural History Department, Royal Scottish Museum, Edinburgh, died on May 10, aged eighty-five years.

DR. ELMER PETER KOHLER, Seldom Emory Professor of organic chemistry at Harvard, died on May 24 at the age of seventy-two.

DR. FRANCIS BAKER LANEY, since 1920 head of the department of geology at the University of Idaho, died on April 24 at the age of sixty-three.

MR. JAMES ERNEST MARSH, University demonstrator in chemistry at Oxford from 1886, died on April 13 at the age of seventy-seven.

COLONEL MARNUSWELL MAXWELL, who died on April 21, was one of the most successful photographers of wild life in East Africa; his photographic studies of the eastern gorilla have never been surpassed.

DR. JOSEPH WILLIAM MELLOR, distinguished scientist and ceramic physicist, died in London on May 24 at the age of sixty-nine.

MR. EDWARD MEYRICK, in his time the greatest authority and the most prolific writer on the Microlepidoptera, died on March 31 in his eighty-fourth year.

MR. THOMAS HENRY DIGGES LA TOUCHE, member of the Geological Survey of India, died on March 30 at the age of eighty-two. His greatest work was the survey of the Northern Shan States of Burma. In 1914 he published "A Bibliography of Indian Geology and Physical Geography with an Annotated Index of Minerals of Economic Value." This was followed by the index to genera and species described in the *Palaeontologia Indica*; and index to the *Records*; and finally, the index to the *Memoirs*.

PUBLICATIONS RECENTLY RECEIVED

Physik; von Dr. Paul Wessel. München, 1938 (Ernst Reinhardt Verlage in München. Price RM. 4.90).

Animal Biology; by L. L. Woodruff. Second edition. New York, 1938 (The Macmillan Co., $3.75).

An Outline of Physics; by A. E. Caswell. New York, 1938 (The Macmillan Co., $3.75).

Isaac Newton; by J. W. N. Sullivan. New York, 1938 (The Macmillan Co., $2.50).

Canadian Geological Survey. Report of Mines and Geology Branch for the Fiscal Year Ended March 31, 1937. Pp. 49. Memoirs as follows: 200. A Reconnaissance of Pelly River Between Macmillan River and Hoole

Canyon, Yukon; by J. R. Johnston. Pp. 19; 1 map. Price 10 cents; 201. Geology and Mineral Deposits of Ville-Marie and Guillet (Mud) Lake Map-areas, Quebec; by J. F. Henderson. Pp. 38; 4 maps. Price 25 cents; 206. Cadillac Area, Quebec; by H. C. Gunning. Pp. 80; 2 maps, 7 plates, 6 figs. Price 25 cents; 208. Gold Deposits of Herb Lake Area, Northern Manitoba; by C. H. Stockwell. Pp. 46; 3 maps, 6 figs. Price 25 cents.

Chemie und Technik der Gegenwart. Vol. 18. Feuerfeste Baustoffe silikatischer und silikathaltiger Massen; von Claus Koeppel. Pp. xvi, 296; 51 figs. Leipzig, 1938 (Verlag von S. Herzel, RM. 17.—15.50).

Aus dem Leben der Vögel; von Dr. Oskar Heinroth. Pp. x, 165; 98 figs., Berlin, 1938 (Verlag von Julius Springer, RM. 4.80).

Proceedings of the Florida Academy of Science. Vol. I, 1936. Pp. iv, 170; 15 figs. (University of Florida, Gainesville. Price $1.00).

Agricultural Analysis: A Handbook of Methods Excluding Those for Soils; by C. H. Wright. London, 1938 (Thomas Murby & Co., 16s. net).

West Virginia Geological Survey. Vol. X. Geology and Natural Resources of West Virginia; by P. H. Price, R. C. Tucker and O. L. Haught. Pp. xi, 462; 61 figs., 231 plates, 1 map. Morgantown, W. Va., 1938.

The National Physical Laboratory, Report for the Year, 1937. Pp. iv, 150. Teddington, Middlesex, England, 1938. Price 2s. 6d. net.

Fearfully and Wonderfully Made. The Human Organism in the Light of Modern Science; by R. von Eulenburg-Wiener, New York, 1938 (The Macmillan Co., $3.50).

Cryptogamic Botany. Vol. I. Algae and Fungi; by G. M. Smith. New York and London, 1938 (The McGraw-Hill Co., $4.00). Vol. II. Bryophtes and Pteridophtes (The McGraw-Hill Co., $3.00).

Introduction to College Physics; by C. M. Kilby. 2nd edition. New York, 1938 (D. Van Nostrand Co., $3.25).

Life, Heat and Altitude; by D. B. Dill. Cambridge, Mass. (Harvard University Press, $2.50).

The Rôle of Scientific Societies in the Seventeenth Century; by Martha Ornstein. Third edition. Chicago, 1938 (The University of Chicago Press, $3.00). The book gives biographic statements concerning many of the famous scientists of the seventeenth century, including Galileo and Harvey, as well as chapters relative to the creation of learned societies and studies of the great universities.

AMERICAN JOURNAL OF SCIENCE

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CALCUTTA CENTRAL LIBRARY

SHEARING EXPERIMENTS ON SOME SELECTED MINERALS AND MINERAL COMBINATIONS.

ESPER S. LARSEN AND P. W. BRIDGMAN.

ABSTRACT.

This paper presents a study of the effect of drastic shearing at room temperature under a mean confining pressure of 50,000 kg/cm^2 on various minerals or combination of minerals. Attempts to form the so-called "Stress-minerals" were unsuccessful; other types of change were observed, however. In all cases the crystal structure was highly broken down, and many cases were found in which the product of shearing stress appeared under the microscope to be a perfectly transparent and isotropic glass with an index of refraction lower than that of the original material. The X-ray examination, however, gave no unambiguous evidence for the production of a true glass.
Cristobolite inverts to a form with higher index, probably a new form of SiO_2. Opal is dehydrated and transformed in one case to quartz. Four pyroxenes are transformed to a phase with much lower index, possibly related to amphibole. Azurite is transformed to some substance with definitely different chemical properties. Gypsum loses water and is definitely changed. Siderite changes to a reddish substance, probably an oxide or hydroxide. Definite orientations are produced in many cases, many of these agreeing with results of Sander.

INTRODUCTION.

In this paper a study is made of the effects of the combination of hydrostatic pressure and shearing stress at room temperature produced by the new apparatus of Bridgman[1] on selected groups of natural minerals and mixtures, in the hope that it may throw some light on processes occurring in nature. We were encouraged in the expectation of positive results, because it had already been established that shearing stress is effective in producing certain reactions in inorganic compounds and also in initiating inversions at temperatures 100° to 150° lower than are effective without shear. The first set of experiments was made in an attempt to bring about some of the reactions that are believed by Harker and others to be favored or even determined by shearing stress. The second set was made in an attempt to bring about, by shearing, inversions and reactions from unstable to stable forms that are too sluggish under ordinary conditions to take place, even in geological time. The third set was designed for a study of the orientation of some minerals under shearing conditions.

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[1] Bridgman, P. W.: Phys. Rev. 48, 825-847, 1935, Jour. Geol. 44, 653-669, 1936, Proc. Amer. Acad. 71, 387-460, 1937.

CONDITIONS OF THE EXPERIMENTS.

The material under investigation takes the form of two thin discs, which are compressed between two hardened steel pistons and an anvil, as described in the papers of reference 1. The pistons are pushed against the anvil by a hydraulic press with any desired force up to the maximum of 50,000 kg/cm^2 on the pistons. Under this pressure the material of the discs flows out laterally from between piston and anvil until it is so thinned down that further extrusion is resisted by friction. A little consideration shows that, if the coefficient of friction is finite, the disc will ultimately come to an equilibrium thickness for any pressure, no matter how high. Because of deformation of the steel, the disc formed at high pressure is not of uniform thickness, but is lens-shaped, the center being thicker where the steel of piston and anvil is depressed more than at the edge. At the maximum pressure, 50,000 kg/cm^2, the final thickness at the edge of the lens was of the order of 0.002 cm, and that at the center perhaps five times as much. The diameter of the disc is 6.35 mm. After the disc has reached its equilibrium thickness at any pressure and while pressure is still applied, shearing stress in addition is now produced by rotating the anvil between the pistons about the vertical axis. At pressures higher than perhaps 10,000 to 20,000 kg/cm^2 in these experiments the friction at the surface of the disc becomes greater than the internal plastic shearing strength of the material, the disc is frozen fast by friction to the surface of piston and anvil, and the rotation of the anvil is accompanied by internal plastic flow in the material of the disc. The shearing distortion accompanying this flow may be very high at the edge of the disc; with the usual thickness and usual rotation through 60° the shearing displacement at the edge of the disc is 120 radians. Toward the center the shearing distortion rapidly drops off, both because of the increased thickness of the disc and the smaller relative linear displacement of top and bottom surfaces of the disc. This is strikingly shown by the fact that by far the larger part of any transformations produced is confined to the outer parts of the discs. This in itself is sufficient to show that the effects are not produced by hydrostatic pressure alone, but shearing stress in addition is necessary.

The fact that the affected material in most cases is confined to the edge of the disc enhances the difficulty of the analyses because of the very minute quantity of material available, which was of the order of 0.001 gm.

The torque necessary to produce rotation was measured, and from this rough values of the shearing strength can be calculated. No attempt is made to reproduce the values of shearing strength in the following, however, because they showed too much variation to be of much significance. In general, the substances examined here are very strong in shear, and are usually brittle, so that the shearing displacement is accompanied by continual snapping and internal rupture; the smooth shearing shown by so many other substances is not often found. In fact, these materials put the utmost demands on the steel parts, which were more damaged than by most other materials. For this reason usually only a single double rotation forward and back through 60° was made at 50,000 kg/cm^2, giving a total shearing distortion at the edge of the order of 250 radians. The total duration of application of shear was of the order of ten seconds. The shearing strength at the maximum pressure averaged between 10,000 and 15,000 kg/cm^2.

The materials were finely powdered, weighed and mixed, in those cases where mixtures in definite proportions were investigated, roughly formed by compression in a mold in an arbor press to discs coherent enough to stand careful handling, and then placed in position between piston and anvil. A number of the powders were prepared "wet," that is, the powders were wet with water before forming to the preparatory disc. Most of this water must have been squeezed out afterwards between piston and anvil, so that it is difficult to estimate how effective the wetting may have been.

The temperature effects may be calculated from the energy required to produce rotation, which was performed at the rate of about 1 radian in 5 seconds, and the thermal conductivity of the steel parts. It turns out that under extreme conditions the rise of temperature is only 30° C., so that temperature can hardly play a part in whatever effects may occur.

The samples were studied under the microscope both before and after shearing, and a selected group were studied by the X-ray powder method by Dr. Alden B. Greninger and Dr. R. R. Hultgren.

The microscopic study showed that all of the discs were made up of a central part that is relatively thick and not much cracked and an outer part that is thinner and is broken into rings by numerous cracks concentric with the center of the disc. The central part has been less changed than the outer part; in most of the discs the minerals at the center show some granulation and shearing, but the particles are relatively large and can be easily identified as those of the powder before stressing. The outer rings show much more effect from the shearing, and the mineral particles are very small. In many of the discs in which more than one mineral was used, the individual minerals are too fine-grained and too intimately mixed to permit identification, and in some, these outer rings appear to be clear, isotropic glass.

The X-ray analysis in general showed the patterns of crystalline material highly broken down. Doctor Greninger reports that he has never seen such highly distorted material—that it must be broken down "almost to the unit cells." Any positive results shown by the X-ray analysis are definite, and one may be sure that the indicated material is present. But negative results mean only that the suspected substance was not present in large enough quantities for detection and under the unfavorable conditions of these analyses this might mean 30 or even 50 per cent. In particular the X-ray analysis is incapable of distinguishing the presence of a rather high percentage of true glass.

I. AN ATTEMPT TO FORM THE "STRESS MINERALS."

The minerals we attempted to form were typical stress-minerals, selected so as to be representative of those which under natural conditions are formed in the full temperature range corresponding to low- to high-grade metamorphism. The minerals used for the mixtures were in part amorphous or hydrous, as such minerals were thought to be more likely to react. The samples were all investigated in the "wet" condition, as water was necessary for some of the reactions, and it was believed that it might act as a catalyzer for others.

None of the expected reactions or inversions to form stress-minerals took place, although several examples of other sorts of change were found. This failure is probably not entirely due to failure to carry on the shearing at temperatures within the range of actual metamorphism, since some of the expected reactions take place in metamorphism under so wide a range of temperatures that one may suspect that some capacity for reaction is left at room temperature. It cannot be denied, however, that a higher temperature, but still one low enough to be within the range of stability of the desired material, would have been more favorable. The use of higher temperatures was prevented by experimental difficulties. In further understanding of the negative results of this section it is to be considered that in nature most of these reactions are so sluggish that failure to reach equilibrium, even in geological times, is common among the metamorphic rocks. For example, andalusite may be only partially replaced by sillimanite. It is further to be considered that the natural conditions with regard to presence of water may not have been sufficiently well reproduced; it is well known that slowly moving solutions play an important part in bringing about metamorphic changes.

The detailed results of the analyses are now given. In spite of the failure to produce any of the expected stress-minerals, there is probably enough interest in some of the other positive results which were found to justify this record in detail. The different experiments are distinguished by numbers.

1. Orthoclase and halloysite in the proportion to form sericite. The central part of the disc still shows the original orthoclase grains not much crushed. Nearer the edge the minerals form a sub-microscopic, fibrous aggregate that resembles the fine fibrous groundmasses of many rhyolites. The fibers are oriented radially and the high index of refraction (γ') is along the length. The mean index of refraction of this sub-microscopic aggregate varies somewhat and averages about 1.535. This is about the mean index of refraction for the original mixture of orthoclase and halloysite; probably no new minerals were formed. There has been an orientation of the orthoclase. Greninger found that the sub-microscopic part of the outer ring of the disc showed the lines of orthoclase but that the lines of halloysite had disappeared.

2. Orthoclase and diaspore in the proportions to form sericite. The central part is still orthoclase and diaspore. The material of the outer rings is sensibly isotropic and has an index of refraction that varies from 1.57 to considerably less. 1.57

is about the mean index of refraction of the original mineral mixture. The material with lower index of refraction may possibly represent the presence of some glass. However, probably no new minerals were formed and little or no glass.

Greninger made X-ray photographs of the original mixture (not sheared) and of the outer nearly isotropic shell and reports: "The pattern of the sheared mixture shows the lines of both orthoclase and diaspore with diaspore predominating. For the original powder, diaspore gave the stronger lines."

3. Halloysite and $K_2CO_3.2H_2O$ in the proportions to form sericite. The outer part of the charge is made up of a fine aggregate with the following optical properties, which are the properties of an aggregate: mean index of refraction varies, but averages 1.54; birefringence rather strong; optically —; 2V moderate. In many parts aggregate interference figures are in the field of the microscope. This is probably a mixture of halloysite and anhydrous K_2CO_3. The crystals have been rather well oriented.

4. Chlorite and sericite in the proportions to form biotite. The central part is made up of grains of green chlorite ($\omega =$ 1.615) and colorless sericite. The outer part is a very fine-streaked mixture of the two minerals. The sericite (and perhaps also the chlorite) are well oriented with γ' normal to the concentric cracks. The aggregate interference figures of the sericite are in large part oriented with the acute bisectrix in the field of the microscope and about 90 per cent show the plane of the optic axis radial and normal to the concentric cracks. Some of the extreme outer part is sub-microscopic and has streaks of opaque dust, as if some decomposition had taken place.

5. Chlorite, K_2CO_3, and SiO_2 in the proportions to form biotite. The small amount of the charge adherent to the piston was nearly or quite isotropic and had an index of refraction of about 1.575. This might be a mixture of the original minerals.

6. Calcite and wood opal in the proportion to form wollastonite. It is a very fine mixture of calcite and opal. The calcite is biaxial and tends to be oriented with the optic axis normal to the cake. These data were obtained from aggregates of very fine grains.

7. Dolomite and wood opal in the proportions to form diopside. There was no reaction. Optical data on the dolomite aggregates are: biaxial, Bx_a nearly normal to the disc. Some of the sheared opal has $n = 1.52 +$.

8. Siderite and opal in the proportion to form $FeO.SiO_2$. After shearing the siderite was changed to fibrous aggregates of a reddish material with a high index of refraction and rather strong birefringence. Particles of opal were still present in the central part of the disc. The siderite was broken down to some unknown material, but there probably was no reaction with the opal.

9. Andalusite. This yielded a thin layer of vitreous material so hard and tightly welded to the steel piston as to require a diamond point to separate it from the piston. The central part is very finely granulated andalusite. The outer part is chiefly finely crystalline to sensibly isotropic and has a mean index of refraction of 1.64. There are some patches and very tiny (up to 20μ) rounded globules of isotropic material, with an index of refraction as low as 1.56. It is probably glass, perhaps due to some impurity; it is in any event improbable that the highly refractory Al_2SiO_5 was fused. Nothing that resembles cyanite was found. An X-ray study by Hultgren of the isotropic outer shell indicates a "probable change." The optical data are uncertain, but show that any new form cannot be sillimanite or cyanite.

10. Colorless diopside and H_2O. The inner part of the disc is diopside strained and crushed ($\gamma = 1.69$). Some of the outer part is sensibly isotropic, but some is very finely fibrous and birefracting. The mean index of refraction of the isotropic part is near 1.62, that of the fibrous part about 1.64. The β index of refraction of the original diopside was 1.678 and γ was 1.699.

The microscopic data indicate that the outer fibrous aggregate is not diopside. The mean index of refraction of a tremolite with about the iron content of the original pyroxene but with some H_2O and a different ratio of CaO to MgO would be about 1.616. The fibrous aggregate is therefore not ordinary tremolite, but it might be an impure tremolite lacking H_2O and of somewhat unusual composition. However, Greninger found that the X-ray pattern of the outer part of the stressed diopside disc is the same as that of diopside.

11. Green augite from Iron Hill, Colorado and H_2O. ($\alpha = 1.688$, $\beta = 1.697$, $\gamma = 1.719$). The central part of the disc is crushed pyroxene. The outer rings are matted radial fibers with extinction angle, negative elongation, β ranging from 1.675 to 1.685. Hultgren found that the original pyroxene and the outer ring of the sheared pyroxene gave the same

X-ray pattern. The same pyroxene sheared dry was like the original mineral except for a little material with low index of refraction.

12. Augite from Renfrew, Canada, and H_2O. ($\beta = 1.725$, $\gamma = 1.74$). The central part of the disc is granulated pyroxene. The outer part is in radial fibrous aggregates with γ normal to the disc and α nearly radial. The mean index of this fibrous material is variable but averages about 1.69 and is lower in the very fine-grained and sub-microscopic parts. Hultgren studied the X-ray patterns of the original pyroxene from the central part of the disc and of the fibrous material of the outer rings and found the latter much more shattered than the former, but could detect no other change caused by the stress treatment.

The pyroxene from Renfrew sheared dry has a thick inner part to the disc that is nearly opaque, due to its thickness, but appears to be unchanged pyroxene. The outer ring of the disc is thinner and is made up of matted fibers radiating from the center, with $\alpha \doteq 1.697$ parallel to the fibers and $\gamma = 1.71$. Some parts are nearly isotropic and have a lower index of refraction.

13. Bronzite from Stillwater Complex, Montana, and H_2O. ($\gamma = 1.681$.) It yielded a disc with a central part not adherent to the piston and an outer part that was welded to the piston. The central part is sub-microscopic to isotropic and has n about 1.64. The outer part, welded to the plunger, resembles a clear glass and has $n = 1.62$. From the X-ray patterns of the original bronzite and the central part of the disc Hultgren concluded that there was probably no change.

Another disc of bronzite had a central part made up of rather coarsely crushed bronzite separated rather sharply from the outer rings that were made up of very finely crystalline to sub-microscopic or isotropic material with an index of refraction of about 1.65.

The bronzite sheared dry has a central part of the disc made up of finely granulated bronzite and an outer ring that is for the most part bronzite but has a little material in radial fibers with γ parallel to the fibers and $n = 1.645$ to 1.655. Some clear parts are made up largely of the material with a low index of refraction.

All four of the sheared pyroxenes studied above have much lower indices of refraction than those of the original mineral. This indicates an inversion to a new phase possibly related to amphibole. However, the X-ray data for all four pyroxenes are negative The outer rings of sheared clinopyroxene are made up of matted fibers with extinction angle and negative elongation.

14. Hornblende, dark green. ($\alpha = 1.679$, $\beta = 1.695$, $\gamma = 1.698$.) Sheared dry it is much like the original hornblende except for some material in the outer shell that is sensibly isotropic and has n below 1.68.

Sheared wet, the central part of the cake was not changed much. The outer part is made up of minute matted, radial fibers with γ parallel to the elongation. The mean index of refraction is 1.673. Hultgren reports that X-ray data on the original and the stressed hornblende show no change.

15. Garnet from Bohemia, pale pink, isotropic crystals with $n = 1.745$. Sheared dry, it gave a fine aggregate of distinctly birefracting material even in the center of the disc with n about 1.72. Greninger states as a result of his X-ray study: "The original pattern showed very sharp lines. The pattern of the sheared garnet gave the same pattern as the original garnet, with practically no change in line sharpness. This material differs from all others examined in that the shearing has had practically no effect on the quality of the X-ray lines." There was probably no change in the garnet in spite of the optical data. Greninger comments that the presence of sub-microscopic cracks is to be considered as an explanation of the low index of refraction.

II. INVERSION AND DEHYDRATION.

The first two investigations in this group were made on forms of silica, since they are promising minerals for the study of shearing as a catalyzer in mineral inversions. They have a simple and uniform composition, their stability relations are well known, and they are chemically stable. They have practically zero rate of inversion under ordinary conditions, as the unstable forms, tridymite and cristobalite, have persisted without appreciable inversion since Miocene time or earlier. Even at temperatures above 1000° C., without a flux, their rates of inversion are not appreciable in the laboratory.

16. Cristobalite. Cristobalite has a specific gravity of 2.34, while quartz has a specific gravity of 2.65; hence the difference in density is large and some change is to be anticipated.

Artificial cristobalite made by heating quartz sheared dry became birefracting and had a mean index of refraction of 1.486. After subjecting a wetted sample to shearing the whole of the disc was made up of matted birefracting material. Most of the material has an index of refraction of about 1.515, but a small part has n greater than 1.53 and another small part has n less than 1.51.

Greninger reports that "the X-ray pattern of the sheared sample shows considerably more resemblance to the tridymite pattern than to the original cristobalite pattern, although it is not possible to state definitely that the sheared material is tridymite. The pattern of the sheared material shows no resemblance to quartz. A fairly definite change was caused by the shearing."

It appears, then, that both the microscopic and X-ray data for cristobalite show a change on subjecting to shear. The microscopic data was thought to mean a partial inversion to quartz. The X-ray patterns resemble that of tridymite, but the material cannot be tridymite, as the index of refraction of tridymite ($n = 1.470$) is somewhat lower than that of cristobalite, while the stressed material has a much higher index of refraction ($n = 1.52$). A reasonable interpretation is that a new form of SiO_2 not hitherto known has been formed.

17. Opal. This, the hydrous form of silica, also has a low density, so that again changes may be anticipated.

A wood opal from Sonoma County, California, was originally sensibly isotropic, had an index of refraction of 1.452, and gave an X-ray pattern resembling that of cristobalite. It contained numerous microscopic tubes of air. After subjecting to shearing, without the addition of water, the inner part of the disc became a mass of matted fibers that are faintly birefracting and that tend to have their high index of refraction and elongation radiate from the center of the disc. The mean index of refraction varies ± 0.005 and averages 1.477. A powder that probably represents the outer part of the disc contains some opal but is made up for the most part of faintly birefracting matted fibers that have a somewhat variable index of refraction which is as high as 1.49 in some parts.

Doctor Greninger examined both the original, unsheared wood opal and the central part of the disc of opal after subjecting to shear. He states, "The pattern of the original opal greatly resembles the cristobalite pattern, but is definitely not exactly the same as the cristobalite pattern. The sheared material has suffered no change other than a considerable shattering. The pattern of the sheared material is considerably different from that of cristobalite sheared (wet)."

These data show that the original "opal" was made up chiefly of submicroscopic cristobalite with the addition of water and that shearing drove off most of the water but did not invert the cristobalite.

Opal variety hyaline from Mexico. Under the microscope the original hyaline shows good birefringence and a fine radial structure. The fibers have negative elongation and an average index of refraction of 1.459. Greninger found that the X-ray pattern shows the sample to be very close to amorphous, with a few very weak and broad bands.

After shearing, the inner part of the disc shows a mottled birefringence and an index of refraction that varies ± 0.01 but averages about 1.492. The outer rings are cloudy, nearly isotropic, and have an index of refraction of 1.51 ± 0.005. Greninger took an X-ray photograph of the outer rings and states: "The X-ray pattern shows the material to be at least partly crystalline. The lines are very weak but sharp; the pattern is almost identical with that of quartz. It is different from the stressed cristobalite, which appeared to be similar under the microscope ($n = 1.52$)." He regards the evidence of the transformation to quartz as perhaps the most unequivocal of all the X-ray results.

18. Azurite. Azurite sheared dry remains blue with some dark opaque streaks and a little green material on the borders. This sheared material effervesces actively in $AsBr_3$ and leaves a brownish residue, while the original azurite is not acted on by $AsBr_3$. There must have been some chemical change or inversion.

19. Goethite, sheared dry, was probably not changed.

20. Gypsum. The disc of sheared gypsum has a central part that is still gypsum. This part is made up of concentric layers that have different birefringences and are themselves made up of fibers across the layering. Another set of layers (twinning?) is at 35° to the main layering. $X = Bx_a$(?) is normal to the disc, 2V appears large, and the extinction angle measured against the layering is large.

The outer rings are filled with black iron(?). They are made up of radial fibers with $\gamma =$ elongation and $X(Bx_0?)$ normal to the disc. They have a mean index of refraction of 1.56 and are not gypsum.

Greninger found that "the central portion of the disc (gypsum) gives fairly good X-ray lines and the black portion (outer rings) gives faint lines, and the lattice has been greatly shattered, but evidence is definite that the pattern is different from that of the white portion. The pattern of the black portion does not resemble the pattern of anhydrite nor that of plaster of Paris (hemihydrite). There is a fairly definite change."

The outer rim (dark part) must be either the monohydride or soluble anhydride.

A number of the substances examined in the attempt to form "stress-minerals" gave results bearing on the question of inversion and dehydration. The following brief recapitulation is therefore made of results already given in section I.

Andalusite after shearing looks like an isotropic glass under the microscope, but its X-ray data indicates that andalusite is still predominantly present.

The pyroxenes and hornblende after shearing have lower indices of refraction than the original minerals. The X-ray data give no positive indication of inversion.

Garnet after shearing has become distinctly birefracting and has a lower index of refraction than the original mineral, but the X-ray data indicate no change in crystal structure.

Siderite is changed by shearing to a reddish material, probably an oxide or hydroxide.

III. ORIENTATION OF THE SHEARED MATERIALS.

As the sheared minerals are all in a very fine state of subdivision, all the optical data are approximate and are derived from aggregates. The orientations observed on these aggregates give only approximate petrofabric data.

21. Sericite. Sheared wet, the sericite plates have a good aggregate orientation. Bx_a is normal to the disc, and the plane of the optic axis is about radial, which is normal to the rings. This makes the gliding plane of sericite the base and the direction of transport the normal to the optic plane and agrees with the data given by Sander.[2]

22. Calcite. Sheared dry, most of the fragments are aggregates. The aggregates appear to have a medium to small axial angle and the acute bisectrix is nearly normal to the disc for many of the plates. Calcite has recently been found to have at least two polymorphic transitions at pressures below 50,000 kg/cm². Orientation phenomena may be connected with the transitions. A similar possibility is to be considered in specu-

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[2] Sander, Bruno: Gefügekunde der Gesteine, Julius Springer, Wien, p. 323, Diagrammen 119, and p. 215, 1930.

lating on the explanation of orientation phenomena in other substances.

23. Dolomite gave the same orientation as calcite—the optic axis nearly normal to the disc.

The orientations of calcite and dolomite appear to agree with those found by Sander for these minerals in metamorphic rocks.

24. Quartz after shearing had a fair orientation with the *c* crystal axis in the plane of the disc and tangential to the outer ring of the disc. (*n* averages about 1.545.) This would make *c* the direction of transport, which is the common orientation in the quartz of some metamorphic rocks.[3]

The following three substances have already been described in another connection in the earlier sections.

Hornblende after shearing yielded matted fibers that have positive elongation and that are oriented radially. The fibers, therefore, appear to be parallel to the *b* fabric axis.

Pyroxenes after shearing tend to have the fibers radial and on extreme shearing give moderate extinction angles and negative elongation and γ nearly normal to the disc.

Orthoclase in mixture with halloysite after shearing yielded a finely fibrous mass. The fibers have positive elongation and are elongated radially (along the *b* fabric axis).

In general summary of the orientation results, quartz is poorly but distinctly oriented, sericite and carbonates are well oriented, and all of these minerals appear to follow the laws of orientation given by Sander. After shearing, hornblende, pyroxene, and orthoclase tend to yield fibers elongated radially.

SIGNIFICANCE TO GEOLOGY.

In nature, the various forms of mylonite, including pseudo-tachylite, are formed under conditions of compression and shearing that closely resemble the conditions of the experiments reported in this paper. Nearly all the types of mylonite-structures were reproduced in our experiments. The ultramylonites and pseudo-tachylites are much like the submicroscopic and isotropic materials produced in the laboratory.

Attempts to form the stress-minerals were not successful. This is not surprising, since the temperatures of the experiments were not altogether favorable and the time of shearing was short. We know that many of the reactions during metamorphism are extremely slow, requiring geological time.

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[3] Sander, Bruno: loc. cit., p. 312, pp. 180-184, 306-307, and 312.

Mica, carbonates, and quartz were oriented by shearing and in general, they follow the common types of orientation given by Sander. Many of the fibrous minerals were oriented with their elongation along the b-tectonic axis.

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ANALYSES IN LAYERS OF A SINGLE CRYSTAL OF CLEVEITE, AUSELMYREN, NORWAY.

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Some analytical work has been done lately on different layers of single crystals of uraninite. Such analyses are of very great interest because they may help to throw light on the formation of the crystals and on the changes that occurred later in the crystals, both by radioactive disintegration and by oxidation or infiltration from the outside.

We have published earlier[1] the results of some determinations of the ratio UO_2/UO_3 in several layers of a single cleveite crystal; and in the following pages complete analyses of the same layers of the crystal will be given with a discussion of the results.

The material for the present work was a cleveite crystal weighing about 7 g, from Auselmyren, Holt, Austagder. It was given to us by the Institute of Geology at the University, Oslo, and we are glad to express here our gratitude for this valuable material.

The crystal showed three cubic faces and was consequently easily centered. It carried very little gangue and very little of alteration products. These latter had a yellow or reddish colour and covered partly some crystalline faces and some fractured faces.

The alteration products were very carefully eliminated and collected, pulverized, and analyzed separately. (I).

The gangue and foreign minerals that adhered to the crystal were also removed and kept for further investigation (II). The crystal when completely freed from gangue and alteration products, was of a deep black lustre. With a pair of steel pliers tiny pieces of the crystal were clipped off parallel to the cubic faces. The material was pulverized and gave the part marked III. Another layer also parallel to the cubic faces was removed in the same way and pulverized, part IV, and the resulting core finally gave part V.

The weights of the different layers were as follows:

I	II	III	IV	V
0.1854 g	0.7479 g	2.1225 g	2.2563 g	1.3648 g

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[1] Microchimica Acta B. 1. H. 1. 1937.

The crystal showed streaks of yellow and orange right into the center; but they were so extremely thin that the percentage of alteration products they represented would be quite negligible. However, they prove that the crystal is not quite unaltered. Whether the yellow product is due to infiltration from the outside and deposition or to radioactive changes within the crystal, is at present doubtful. The question is of very great importance to the age estimations, to which we shall revert later. Determinations of the ratio UO_2/UO_3 in the different layers of this same crystal, which have been made earlier, rather suggest an oxidation from the outside. The value of the ratio UO_2/UO_3 diminishes from the core, 1,43, to the outside layer, 1,35, showing that the amount of UO_3 grows larger towards the outside. It must be emphasized that what is called outside layer in the former publication, corresponds to part III in this, the completely black outside layer of the crystal, mechanically freed from gangue and all alteration products.

The three parts, III, IV, and V, are all black, but the colour deepens and darkens from III to V, from the outside layer to the core, probably due to this increase in the ratio UO_2/UO_3.

Analyses have been made of the five parts; they are complete, however, only for the three layers of the crystal itself, III, IV, and V, where the results are given in the usual way. Of part I two analyses have been made, but the very slight quantity, 0.18 g, did not permit special analyses, as e.g., the determination of the ratio UO_2/UO_3. Only one analysis has been made of part II; it is not complete and the numbers given are only approximate.

The analyses have been performed as microanalyses, the substance taken for each analysis being about 40 milligrams. The procedure of an analyses is, in the main, as follows:

The mineral is weighed in a platinum crucible and treated twice with 2 ml nitric acid (1 : 1), the solutions being evaporated to dryness each time. The residue is moistened with concentrated nitric acid and 10 ml nitric acid 1 per cent is added. The solution is filtered off from the undissolved residue, which is heated and weighed and the silicic acid is then determined by evaporation with hydrofluoric acid. The filtered solution is heated to about 70° C. and kept in contact with gaseous hydrogen sulphide during half an hour; the sulphide precipitated is filtered off, converted into sulphate, and weighed as lead sulphate.

In the solution the remaining metals are precipitated as hydroxides and these are dissolved in dilute nitric acid. Thorium and the rare earths are next precipitated with hydrofluoric acid; the fluorides are converted into sulphate and dissolved in water. Thorium is separated by hydrogen peroxide and weighed as ThO_2, while the remaining earths are precipitated with ammonia and weighed as oxides. The filtrate from the fluoride precipitate is evaporated. The residue is heated with sulphuric acid, and the resulting mass is dissolved in water and hydrochloric acid. Iron and uranium are separated in the usual way with ammonium carbonate. The carbon dioxide is expelled from the solution and the uranium is precipitated with pure ammonia and weighed as U_3O_8. Water and change by ignition are determined by difference in one and the same sample of the mineral. All reagents used have been tested and in part specially prepared.

As an example of the accuracy obtained in the analyses, from which an average is calculated, the percentage numbers for part V are here given in detail.

TABLE 1.

Cleveite, Auselmyren Part V, Core.

	A	B	C
Insol.	0.00	0.05	0.08
PbO	13.08	12.94	13.05
ThO_2	3.03	3.03	
Rare earths oxides	2.30	2.18	
Fe_2O_3	1.18	1.22	
U_3O_8	81.63	81.73	
H_2O	0.17	0.11	
Increase by ignition	1.66	1.67	

In tabulating the results of the analyses the question also arises how much of the uranium is present in quadrivalent state and how much in hexavalent. This has been found by separate determinations of the ratio UO_2/UO_8. These determinations have been done earlier for the three layers V, IV, and III of this same cleveite crystal. The results have been published already[2] and for all details we shall refer to the earlier publications; only the principle of the method employed will be given here:

The mineral is decomposed by being heated with sulphuric acid. Water is added until the solution contains ten per cent of sulphuric acid, and the uranous oxide UO_2, present is determined by titration with 1/100 n. permanganate solution. The liquid is filtered off from lead sulphate and unattacked mineral and passed through a Jones reductor.

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[2] Microchimica Acta B I H. 7; for further details see also Archiv f. Math. og Nat. vid. 12(5) 1935.

The reduction proceeds below the quadrivalent state of uranium but does not reach the trivalent. The reduced compound is, however, oxidised again by blowing clean air through it for five minutes.

A new titration with 1/100 n. permanganate solution gives the entire uranium as uranous oxide and from the difference between the two titrations the amount of uranic acid, UO_3, is deduced.

TABLE 2.

Cleveite from Auselmyren.

	Black, fresh-looking material			Gangue and impurities	Alteration products
	Core	Middle layer	Outside layer		
	V (1.3648 g) in %	IV (2.2563 g) in %	III (2.1225 g) in %	II (0.7479 g) in %	I (0.1854 g) in %
Insol.	0.04	0.00	0.24	2.50	0.31
SiO_2	....	....	....	9.00	3.15
PbO (Pb)	13.02 (12.09)	12.86 (11.94)	12.66 (11.75)	9.50 (8.82)	20.65 (19.17)
ThO_2 (Th)	3.03 (2.66)	2.96 (2.60)	3.20 (2.81)	3.50 (3.08)	6.96 (6.12)
Rare Earth ox.	2.24	2.42	2.26	2.00	1.43
Fe_2O_3	1.20	0.82	0.45	13.16	3.86
U_3O_8 (U)	81.68 (69.27)	81.55 (69.16)	80.92 (68.62)	55.00 (46.64)	52.23 (44.29)
H_2O	0.14	....	0.20	0.75	2.13
Loss by ignition	....	....	....	....	9.84
Increase by ignition	1.67	0.89	1.14		
UO_2	48.43	47.61	46.35		
(U)	(69.95)	(69.91)	(69.49)		
UO_3	32.75	33.57	34.40		
UO_2/UO_3	1.48	1.41	1.35		
UO_2 corr. (U)	47.95 (42.27)	47.10 (41.52)	45.77 (40.35)		
UO_3 corr. (U)	32.44 (27.00)	33.21 (27.64)	33.97 (28.27)		

In the first part of table 2 the results of the analyses have been put together in the usual manner. The uranium determined gravimetrically has been calculated as U_3O_8, the iron as Fe_2O_3. This has been done in order to permit comparison with other analyses given in the literature. We know, however, that this cleveite contains much more uranium in the quadrivalent state than would correspond to U_3O_8. This is borne out by the next part of table 2, where the results of the UO_2/UO_3 determinations have been tabulated.

It will be noticed that the uranium content when calculated from the titrations differs slightly from the value found by gravimetric analyses. In these analyses, as in others earlier published,[2] the value found by titration is always a little higher. This to our mind is due to the ferrous iron in the mineral. We believe—and we hope later to give reasons for this—that iron is present in cleveite both as bivalent and trivalent, as FeO and Fe_2O_3. The amount of iron in this cleveite is small, however, and any error in the state of oxidation used in calculating the results of the analyses would be insignificant.

The presence of FeO must, however, introduce a slight error in the values found for UO_2 by titration and consequently, in both UO_2 and UO_3 determinations. We are therefore inclined to believe that the nearest approach to a correct value for the uranium that we can reach at present is given by the corrected numbers in table 2 (UO_2 corr. and UO_3 corr.). They are deduced from the uranium contents gravimetrically found, and the ratio UO_2/UO_3 which only in a negligible degree will be influenced by the ferrous oxide present.

Turning then to the other constituents of the mineral, we notice that the amounts of insoluble, of silica, and of water are very slight in the black part of the crystal, V, IV, and III; this corroborates the view that this inner part of the crystal is not much altered. The amounts are higher in the other layers, I and II, and silica is especially high in II, in the gangue.

For some of the metals the results are striking: iron and lead diminish gradually from the core to the outside, from V to III; the differences are small but significant. If then we proceed to part I, we shall find that the increase in the amounts of those two elements is overwhelming. Lead oxide which is present in about 13 per cent in V to III suddenly rises to more than 20 per cent in I, iron oxide from about one per cent in V to III rises to nearly four per cent in I. The contents of thorium oxide vary only slightly in the layers of the black part, but rise to more than the double in part I.

It will be noticed that we have given no sums for the analyses. This is not without intention. In studying uraninites we have come to the conclusion that the usual way of calculating the sums is incorrect, this is mostly but not exclusively due to the fact that uranium is not present as U_3O_8.[3] Determinations of the oxygen in the mineral will perhaps give more definite information about the correct way of calculating the sum of the analyses. We hope to revert to this question in a later publication.

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[3] See also Hillebrand: Bull. U. S. Geol. Survey 7-8, 1891.

Table 3 gives the results of some analyses performed on material of the same provenance, cleveite from Auselmyren, but not on the same crystal. In characterizing the mineral they may perhaps be of a certain value.

The material was examined and the black fresh-looking part was carefully separated from all yellow and orange-coloured alteration products. In table 3 A corresponds to the parts V + IV + III in table 2 and B to part I.

TABLE 3.

Cleveite from Auselmyren.

	A Black, fresh-looking part	B Yellow alteration products
Specific gravity	8.24	
Carbon dioxide	0.56	
UO_2	32.03	4.68
UO_3	46.12	63.31
UO_2/UO_3	0.71	0.074

The specific gravity found in this sample is in accordance with determinations in other cleveites.

The amount of carbon dioxide is also regular; all cleveite specimens examined contain about 0.5 per cent.

A significant fact emerges from the uranium analyses. The ratio UO_2/UO_3 in A is 0.71, in B 0.074. This means that in the altered products nearly all the uranium is present in hexavalent state.

We have determined the UO_2/UO_3 ratio in a large number of cleveites and the values found have varied from 0.47 to 0.82[2] in the black part of the specimens.

It will be noticed that the crystal on which analyses in layers has been performed, shows a ratio which is decidedly higher viz.: 1.35 to 1.48. We can give no explanation of this; it proves that even in material from the same mine the values of the ratio UO_2/UO_3 can differ considerably.

When turning now to the discussions of the analyses we first of all want to point out the difficulties in comparing different authors' analyses of separate layers of crystals because in so many publications, the layers are not sufficiently well characterized. We shall not attempt to draw any conclusions from the earlier work, where dissolving agents, mostly nitric acid, were used. We know from many experiments that acids, even acids not very concentrated, have a selective solvent action on the uraninites. Of the remaining analyses in layers those performed on Wilberforce uraninite by Alter and Yuill[4] and by Hecht and Kroupa[5] and on Morogoro uraninite by Hecht[6] are comparable to ours.

From the analyses by Alter and Yuill on Wilberforce uraninite a very striking fact emerges regarding the thorium contents. Three consecutive layers are analysed and much more thorium is found in the middle layer than in the two others, viz.: 15.25 in middle to 5.22 in outside and 10.46 in core. The same was noticed also by Alter and Kipp in an earlier analysis on the same mineral where, however, separation was made by fractionate dissolving in nitric acid. The fact is very difficult to explain.

In the cleveite analysed by us, it will be noticed that the thorium percentage in the different layers of the black part of the crystal varies only slightly; but in part I, alteration products, the percentage is much higher. It might perhaps be suggested that some thorium in this part was derived from other neighboring minerals, but it does not seem likely, because part II, which undoubtedly contains some of these, has less thorium than I.

Hecht and Kroupa in their analyses of Wilberforce uraninite have not found very large differences in the thorium contents of the four inner layers of the crystal. It is at first a little disappointing to notice that there are differences in the results on the Wilberforce material when analysed by Hecht and Kroupa and when by Alter and Yuill. It seems to us, however, not unlikely that apparent incongruities might be explained by the different way in which the separation of the layers concerned has been made.

In this connection we also want to point out a difficulty, that when comparing other results to those of Alter and Yuill, these authors have given analyses only of the radioactive constituents in the layers. It would have been very interesting indeed to see what discrepancies in the other constituents in the middle layer made this big thorium content possible. In order to elucidate this question we shall undoubtedly have to await further details.

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[4] Alter & Yuill: J. Am. Chem. Soc. V. 59, p. 390, 1937.

[5] Report of the Comm. on the Measurement of Geol. Time, 1937.

[6] Hecht: Sitz Ber. Akad. Wiss. Wien B. 140. 2 Aa p. 599, 1931.

Hecht and Kroupa have made very complete analyses of layers of Wilberforce uraninite. It seems to us that these authors have treated their material in much the same way that we have done our cleveite, giving much attention to the necessity of keeping the outside products quite separate from the layers of the crystal itself. On the other hand, the specimen that we have seen of Wilberforce material, does not show the same kind of alteration products as cleveite. And, moreover, Hecht's and Kroupa's analyses bear out that the "outside" is formed by other minerals, poor in uranium and rich in calcium, silica, and iron. We do not believe that our section I, "alteration products," can be compared to any layer in the analyses performed on the Wilberforce material.

The only remaining analysis then is the other, earlier one by Hecht on Morogoro material, the analysis marked M XIV.[6] The crystal analysed evidently had an outside layer of alteration products, K and g. Sch., and an inner part. Of this inner part two layers were black, 1 (the core) and I schw. Sch. (middle), and must have consisted of rather unaltered mineral. But the inner part also had softer, green-looking spots which must have contained alteration products of the mineral, g. 1. We do not believe that the two parts, g. 1. and g. Sch., in Hecht's analysis have any corresponding parts in ours. But his black part can be compared to our black part and his K to our I. A few parallels can be drawn: the amount of water, silica, and insoluble material is higher in the altered parts than in the black ones; further, in Hecht's analysis the amount of rare earths is higher in the altered parts, in ours the thorium. The uranium in K and I is lower in amount than in the black parts of the two minerals, and as the lead is either about the same (K) or higher (I) the lead/uranium ratio is higher; it is slightly higher in Hecht's analysis, considerably higher in ours.

Table 4 gives the lead ratios and the deduced ages of the mineral. It must be borne in mind that no atomic weight determination having been performed on the mixture of lead isotopes in the mineral, the exact proportion of radium G in the mixture is not known. The age estimations have, therefore, no absolute value, but they are of interest for the comparison of the different parts of the crystal.

The lead ratios for the three layers of the black part of the crystal are:

TABLE 4.

	V	IV	III
$\frac{Pb}{U + 0.36\,Th} =$	0.1721	0.1703	0.1668
giving approximate ages in million years =	1308	1294	1283

These do not differ much from the results deduced for the whole of the black fresh-looking part of the crystal, parts V + IV + III, which are, the amounts being taken into consideration: lead ratio: 0.1702, approximate age: 1293 million years. The difference is only one per cent.

Quite different is the lead ratio in the two layers not belonging to the fresh-looking, unaltered crystal. The ratios are higher and are especially high in part I, the yellow alteration product, where it runs to 0.4123. It must be noticed, however, that the amount of alteration products and gangue on the crystal used, was very slight; an analysis of the whole crystal would have given a lead ratio of 0.1760—corresponding to an approximate age of 1338 million years, a discrepancy of 3.4 per cent from the value of the black part. In most crystals, however, the proportion of alteration products will be higher, and it is clear that in many cases an analysis of the whole lump of mineral would give a much higher lead ratio and consequently a higher value for the age of the mineral.

We believe that the first idea for most chemists would be to use only the fresh-looking black material for an age determination. It is, however, extremely difficult to say whether this would be the most correct.

The alteration products are apparently built up by the original constituents of the crystal itself, but in quite new proportions. There is less uranium, more thorium and iron, and much more lead. The ratio UO_2/UO_3, given by table 3, shows furthermore that most of the uranium is oxidised and present in the hexavalent state.

It will perhaps be suggested that constituents like iron, thorium, and lead might have been brought in from the surrounding minerals. We have no means of testing this for thorium and iron. But as for lead it must be kept in mind that atomic weight determinations on Katanga and Morogoro uraninites by Hönigschmidt and co-workers,[7] and by Baxter and Alter[8] have proved that lead in the yellow alteration products of these minerals consisted of pure radium G (the atomic weight of lead in this part being even lower than in the black part of the mineral). This makes it nearly impossible that the lead should have originated in other minerals; it is overwhelmingly probable that it is radium G from the crystalline black part of the mineral. The same would probably be true for the cleveite crystal that we have analysed.

In order to explain the experimental data given in the preceding pages, it is necessary to admit that several influences have been at work on the crystal after it came into existence. Out of these influences we should like to draw attention to the following:

1. *Selective solvent action.* It seems to us beyond doubt that the crystal has been subject to a selective leaching from the outside. This, furthermore, does not disagree with earlier experience. Some years ago we made a careful study of a group of uranothorites from the Arendal district in Norway.[9] The radium contents were determined and other attempts were made to find the relative amounts of the radioactive substances in the minerals.

The results proved that the minerals had been subject to alteration, probably due to a leaching by ground-waters, and further *that this leaching had more particularly affected the radium and the lead.*

Lately, direct experiments[10] in this laboratory on uraninite crystals have proved that those can be altered by the influence of water vapour under pressure. The alterations found are in the main in agreement with the results of the analyses reported and with the above explanation. The direct experiments are few as yet, but they will be continued.

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[7] O. Hönigschmidt u. Sachtleben u. Bandrexler. Z. anorg. u. allgem. Ch. B. 214, p. 104, 1933.

[8] Baxter and Alter: J. Am. Chem. Soc. Vol. 5, p. 2785, 1933.

[9] Gleditsch and Qviller: Phil. mag. S. 7. Vol. XIV, p. 233, 1932.

[10] E. Føyn: Norsk geol. Tidsskr. 17, p. 197, 1938.

2. *Radioactive changes.* Besides this selective leaching another quite different action has also to be considered, namely the changes following the radioactive transformations which are going on continuously in the mineral.

Among the disintegration products of uranium one is gaseous—the *radon.* Being a gas, it might partly escape from the crystal; it would then give a layer of active deposit which would in time give radium G.

This process is doubtless going on; it is difficult, however, to say anything definite on the importance of this second source of radium G. From determinations of the amount of helium in the radioactive minerals, and more especially from comparisons of the helium/uranium ratio to the radium G/uranium ratio, we know that there is a somewhat large escape of helium from many minerals.

Earlier work seems to indicate that the loss of helium increases with the age of the mineral considered. Now, for minerals comparable in age to our cleveite, the amount of helium found is only about 10 per cent of the value to be expected, i.e. 90 per cent of the produced helium has escaped.

As for radon it must certainly be supposed that this heavy gas will diffuse much more slowly than helium, but all the same the possibility of a certain loss of radium G in the inner part of the mineral through the escape of radon, cannot be overlooked.

We should like here to repeat that the amount of alteration products in this cleveite is very slight, and the extra amount of radium G found in this layer would only slightly increase the amount of radium G in the whole crystal. On the other hand it must be remembered that alteration products are very easily carried away and thereby lost to later analyses.

As a combination of the two influences mentioned above, the possibility might also be considered that a leaching process has contributed an unknown factor which later has undergone radioactive change. In this connection we should like to call attention to the thorium in the different layers of our cleveite. The thorium percentage rises from about three per cent in the inner part to seven per cent in the alteration products. If by some infiltration from the outside, thorium and its isotope ionium had been deposited in the outside part of the crystal, the amount of thorium would necessarily increase; and likewise the amount of radium G due to the transformation of the ionium, would increase the amount due to the transformation of a certain part of the uranium, initially present.

The influences and actions mentioned can be studied in single crystals, and analyses in layers ought to be continued. At the same time the possibility of variation of different crystals occurring in the same pegmatite dike will have to be considered. This variation may be primary or due to later replacement processes. As yet very few experimental data are available for elucidating this part of the problem.[11]

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[11] See Kirsch and Lane: Proc. Am. Acad. of Arts and Sciences, Vol. 66, no. 10, 1931, and Reports of the Committee on the Measurement of Geologic Time.

OSLO, NORWAY.

GEOLOGY OF THE LEBANON GRANITE, HANOVER, N. H.

E. P. KAISER.

TABLE OF CONTENTS.

Abstract.
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VI. Structure: General Relations.
Fabric Diagrams.
Secondary Production of Foliation.
Form of Intrusive.

ABSTRACT.

A granite gneiss and its border rocks are described and the effects of contact and regional metamorphism evaluated. Albitization is found to have been an important process. Structure is discussed with the aid of a detailed structural map and petrofabric diagrams. Intrusion is shown to have occurred prior to the last major deformation.

I.

INTRODUCTION.

As recently as 1932 the crystalline rocks of New Hampshire were assigned to the Pre-Cambrian.[1] Since that time work by Professor Billings of Harvard and by parties under his direction has shown that the rocks of central New Hampshire, and probably of the whole state, are of Paleozoic age.[2, 3] Abundant igneous rocks, both volcanic and intrusive, occur and range in age from Ordovician to post-Devonian. The subject of this paper is a granitic intrusive generally called the Lebanon granite because formerly quarried near the town of that name.

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[1] Billings, M. P.: Paleozoic Age of the Rocks of Central New Hampshire. Science, Vol. 79, pp. 55-56, 1934.

[2] Billings, M. P., and Williams, C. R.: Geology of the Franconia Quadrangle, New Hampshire. State Planning and Development Commission, Concord, N. H., 1935.

[3] Billings, M. P.: Geology of the Littleton and Moosilauke Quadrangles, N. H. State Planning and Development Commission, Concord, N. H., 1935.

The area described is located just east of the village of Hanover, New Hampshire, in the west central part of the State, and occupies the northeast portion of the Hanover, New Hampshire-Vermont quadrangle and the northwest portion of the Mascoma, New Hampshire-Vermont quadrangle (Fig. 1). The Lebanon granite itself crops out in a roughly oval area, seven by three miles. It intrudes and is wrapped by bands of schistose metasediments, which are continuous with schists dated as Ordovician by Hadley in his work on the Cube quadrangle to the north.[4]

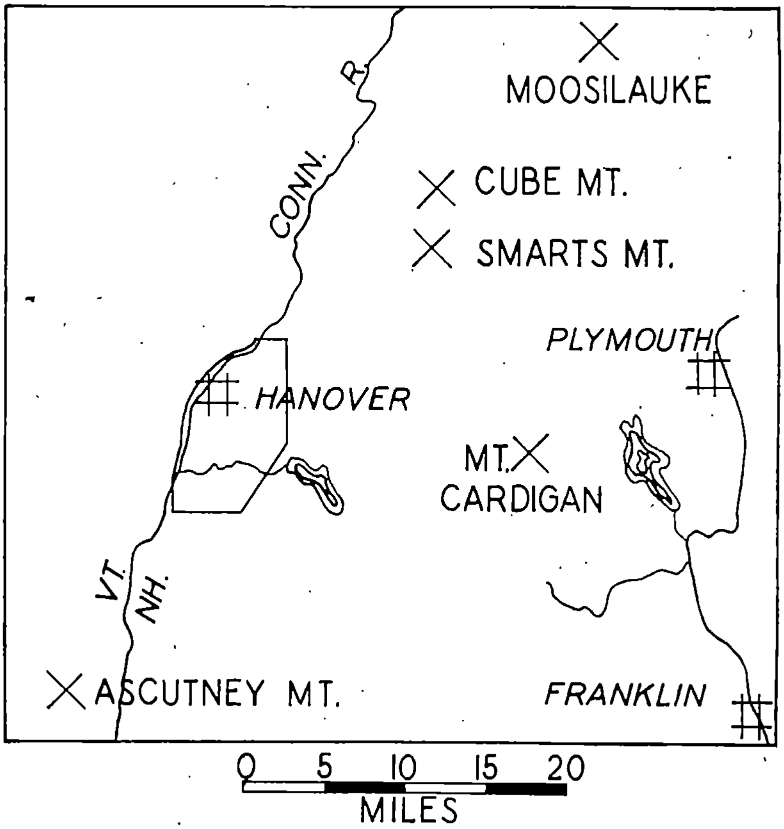

Fig. 1. Index map of west-central New Hampshire. Area of present study is outlined.

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[4] Hadley, J.: Geology of the Cube Quadrangle. To be published.

Between the true granite and the undoubted schists occurs a zone of intermediate material, which will be termed the "border zone." This zone is composed of gneissic rocks; its origin will be discussed in detail.

PREVIOUS WORK.

C. H. Hitchcock, in his study of the Hanover quadrangle, treats the Lebanon granite briefly, and considers it a 'protogene gneiss,' of batholithic type.[5]

J. W. Merritt published a study of the Hanover district in 1921.[6] His map shows a ring of sedimentary formations around the granite core, which he describes as a laccolith. He explains the gneissic texture as due to pressure while the granitic core was still partly liquid, and states that little metamorphism occurred after intrusion.

Merritt's paper is the latest published work on this area. Carleton Chapman has a paper in preparation on the geology of the Mascoma quadrangle, which covers part of the present area.

In the course of mapping of central New Hampshire quadrangles, Professor Billings has grouped the intrusives into magma series of several different ages.[2, 8] Of these, the Oliverian and New Hampshire series are those to which the Lebanon granite may belong. These two series have been separated chiefly on mode of occurrence.

The Owls Head granite, in the Moosilauke quadrangle, a member of the Oliverian series, crops out in a nearly circular area, and has domed up formations of Devonian age. These occur in a simple pattern which contrasts with the generally intense folding in this region. For this reason, and also because of the strongly granulated character of the granite, Billings concludes that it was intruded into unfolded rocks, at a time prior to the major period of compression.

The members of the New Hampshire series characteristically show an elongated outcrop pattern and contacts essentially parallel to the regional foliation. Billings concludes that these bodies were intruded during the last stages of folding.

Foliation is generally present in rocks of both series, and is parallel to the contacts. Billings considers the foliation in the

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[5] Hitchcock, C. H.: Geology of the Hanover Quadrangle. Vt. State Geol., Sixth Report, pp. 139-186, 1908.

[6] Merritt, J. W.: Structural and Metamorphic Geology of the Hanover District, N. H. Vt. State Geol., Twelfth Report, pp. 1-36, 1921.

Bethlehem gneiss to be a primary flow structure along which movement occurred after consolidation.

The structure of the Lebanon granite is intermediate between the types characteristic of the Oliverian and New Hampshire series. Similarities with the Oliverian series consist of: quaquaversal attitude of country rock, with simple outcrop pattern; granulation of mineral constituents; and other evidence of deformation of the solid rock. Similarities with the New Hampshire type are: elongated shape, parallel to regional structure; and generally steeply dipping contacts nearly parallel to foliation.

FIELD WORK.

Field work represented by this paper was carried on during the fall and spring of 1935-36, and during five weeks in the summer of 1936. Laboratory work has been done at intervals since then.

The writer hopes that the present paper may serve as a useful unit in the growing body of detailed information about the metamorphic rocks of New Hampshire.

ACKNOWLEDGMENTS.

For advice and criticism during preparation of this paper, the writer is especially indebted to Prof. H. M. Bannerman, of Dartmouth College. It is a pleasure also to acknowledge assistance rendered by Prof. E. T. Apfel, of Syracuse University; Prof. Carl Tolman, of Washington University; and Prof. H. W. Fairbairn, of Massachusetts Institute of Technology.

II.

SCHISTOSE ROCKS.

Reference to the areal map, Fig. 2, will show the reader that the Lebanon granite is bordered by metasediments, which are divided into an outer carbonaceous phyllite group and an inner quartz-mica schist group. The boundary between them is a stratigraphic horizon, and is parallel to less important boundaries defined in detailed mapping within these two groups. To the west of the massif, outside and stratigraphically above the phyllite group, occurs a group of interbedded hornblende schist and quartz-feldspar-muscovite schist, which is probably

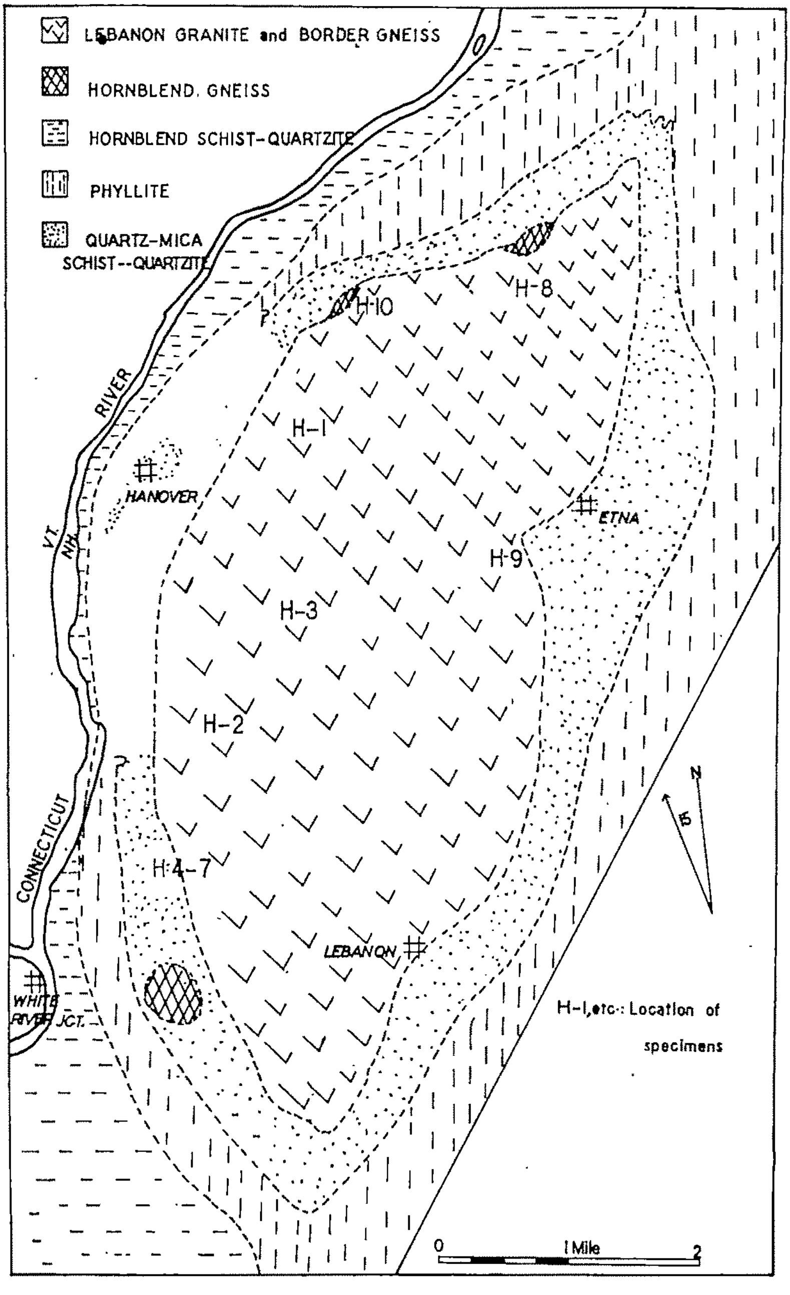
LEBANON GRANITE and BORDER GNEISS
HORNBLEND. GNEISS
HORNBLEND SCHIST-QUARTZITE
PHYLLITE
QUARTZ-MICA SCHIST--QUARTZITE
CONNECTICUT RIVER
VT.
NH.
HANOVER
ETNA
LEBANON
WHITE RIVER JCT.
H-1
H-2
H-3
H-4-7
H-8
H-9
H-10
N
15
0
1 Mile
2
H-1, etc.: Location of specimens

Fig. 2. Areal geologic map of the Lebanon granite and nearby rocks.

volcanic in origin. This group does not occur on the east side of the area studied.

The two inner groups have been traced entirely around the massif; a zone of biotite-quartz schist forms the immediate border rock. Bedding directions in the metasediments are generally parallel to the border of the massif, the only notable exception occurring on the east side near the town of Etna.

The carbonaceous phyllite is typically fine-grained, dark colored, banded in many places, and interbedded with quartzitic layers. On the south, west, and northwest sides of the area, phyllite occurs interbedded with hornblende schist. Garnet, magnetite, and biotite are common constituents of the group in general.

The inner quartz-mica schist group consists of three units, which interfinger at their boundaries: an outer biotite-quartz schist; a central quartzitic member, generally fine-grained; and an inner biotite quartz schist. These rocks show in many places banding, which is undoubtedly original bedding.

Hornblende is the principal dark mineral instead of biotite in places, especially on the west and southwest sides of the area. The presence of the central quartz-rich layer is obvious, however, even where much hornblende has developed.

The inner quartz-biotite schist layer forms the immediate boundary of the gneisses at the present level of exposure. The border zone gneisses are interpreted by the writer as the products of contact action, especially albitization, on a quartzose sedimentary rock very similar to the quartz-biotite schist. Detailed description of these rocks will be deferred until the granitic rocks themselves have been discussed.

MINERALS DEVELOPED IN SCHISTS.

The minerals developed in the schistose rocks are, in order of abundance: biotite, hornblende, muscovite, garnet, epidote, calcite, plagioclase, kyanite, chlorite. Pyrite, magnetite, and molybdenite occur rarely.

Biotite is most abundant in the biotite schists, where it occurs in small unstrained flakes, well oriented. Unoriented biotite metacrysts are scattered through the carbonaceous phyllites. In places there appear large biotite plates that have developed approximately at right angles to the foliation; these occur chiefly in the carbonaceous rocks. As seen in thin section, these plates are partly of skeleton form, containing quartz inclusions, and are commonly strained. They probably were produced by contact metamorphism during the granite intrusion, though they may also be the result of metacryst formation during regional metamorphism.

The small fresh flakes of biotite, in common with those in the granite and border gneisses, are considered to have taken their present form during dynamic metamorphism, as discussed more fully below.

Hornblende occurs in large quantities in many places, both with biotite, and as the only dark mineral. It occurs both in the schists and in the border gneisses. In most places it is well oriented and produces lineation; locally it lies in the foliation plane but has no linear orientation.

Garnet has irregular distribution and size, apparently depending on rock composition rather than on spatial relations. The same is true of kyanite, which was noted only on the east side of the area, in quartzitic schist. Epidote is widespread and abundant, and occurs both as a rock constituent and in veins. Chlorite and plagioclase occur sporadically. Calcite is most abundant in the western part of the area, especially in the hornblende schist group. Pyrite, chalcopyrite, and molybdenite are generally rare occurrences; a fairly large area of quartzite south of Etna, however, is impregnated with pyrite.

Further discussion of mineral development will be found below in the section on metamorphism.

MINOR INTRUSIVE ROCKS.

Some of the hornblende-rich rocks have compositions and textures suggesting derivation from igneous rocks. They are indicated on the map as hornblende gneisses.

On south Crafts Hill, in the southwest part of the area, poor exposures occur of a coarse hornblende-rich rock with either a faintly gneissic or a massive structure. The gneissic structure serves to show that these are not merely coarse-grained variants of the late dikes which are described below. Thin sections of the rock reveal a great variation in composition. Quartz, even where abundant, is chiefly included within hornblende. Some of the massive rocks contain large plagioclase grains. Analysis of one of these sections shows:

	10H
Quartz	3%
Labradorite	26
Hornblende	69
Biotite	1
Epidote	1

The feldspar occurs in large irregularly lath-shaped grains, somewhat epidotized, and showing in some cases bent lamellae; it is a basic labradorite. In most cases the feldspar laths are subhedral against hornblende, which occurs in large felted masses and to a lesser degree as medium-sized grains. The hornblende is clearly secondary, probably replacing some former ferromagnesian mineral such as pyroxene. The feldspar formed before the latest regional deformation, is shown by its bent lamellae; while the hornblende is unstrained and must have taken its present shape since deformation occurred.

The gneisses on Pinneo Hill, in the northern part of the area, are similar to those on Crafts Hill. Massive coarse hornblende rock grades into strongly gneissic rock near the borders of the hornblende-rich area. Fine-grained layers occur which are easily mistaken for the lamprophyre dikes, except for the presence of foliation.

Because of structure and composition, these gneisses are considered to be igneous. The presence of associated effects probably of contact-metamorphic origin and therefore probably due to the granitic intrusion—especially production of large skeletal biotites, and of hornblende from some previous mineral—suggests that they preceded the granite.

The youngest bedrock in the area is a fine-grained, dark greenish-gray lamprophyre, which occurs in dikes usually of irregular form. It contains intermediate plagioclase laths in a groundmass of hornblende, biotite, and abundant opaque material. Phenocrysts of subhedral quartz and anhedral plagioclase are found in places. The dikes have strongly chilled margins and cut all other bedrock types.

III.

GRANITIC ROCKS: GENERAL.

The intrusive itself consists of coarse-grained, light-gray biotite granite, generally gneissic, subporphyritic, and of quite variable composition. This variation affects all the major constituents of the rock, but its most noticeable result is in the color differences produced by change in biotite content. The variation may occur in two ways: quite irregularly with production of masses of light-colored rock in dark or vice versa; and with banded arrangement, producing a streaked appearance.

Microcline phenocrysts are subhedral or anhedral and vary in size up to one-half inch. Biotite is segregated into streaks or lenses, and is well oriented. Quartz aggregates are often noticeably elongated parallel to the foliation, but microcline shows no apparent orientation.

A striking feature of the granitic rocks, and also of the intermediate gneisses here called the border gneisses, is the presence of abundant knots or lenses of fine-grained biotite-quartz-rich material, most of which are less than three inches long. Bands or schlieren of similar material and of various dimensions also are abundant. Both knots and schlieren are as abundant in the center of the area as near the border. They are in most cases nearly parallel to the general foliation. In the few cases of non-parallelism, biotite orientation parallels the general gneissic foliation rather than the long axis of the knot or schliere.

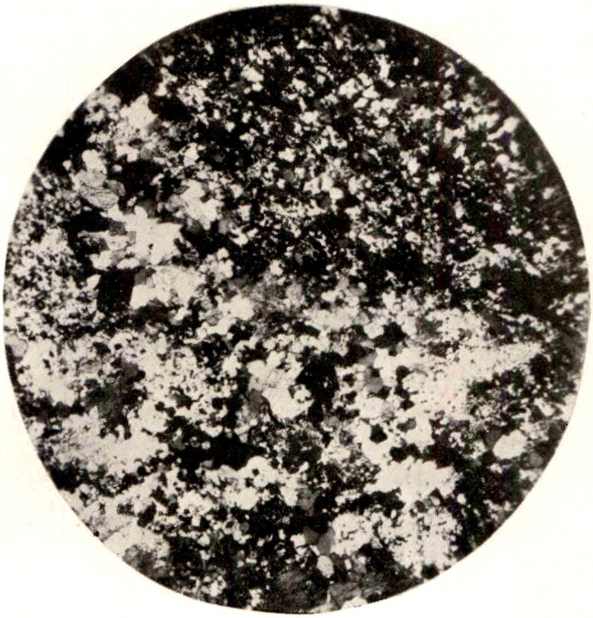

Fig. 3. Contact of medium-grained granite and knot. Crossed nicols, x 18.

Inspection of thin sections of both types reveals a fine-grained aggregate of quartz, biotite, and feldspar, with fairly definite separation from the coarser-grained host rock, as shown in Fig. 3. Quartz amounts to approximately 50 per cent, biotite to ten or 15 per cent. The remainder is feldspar, both microcline and plagioclase, in fine granular condition.

Both knots and schlieren contain more biotite and quartz than the average Lebanon granite. Their composition approaches that of the biotite-quartz schists which border the intrusive. Knots are found far out into the biotite-quartz border gneisses, where segregations could not have been carried. These factors support the conclusion that knots and schlieren are remnants of inclusions of country rock, some of which were strung out by flow into streaks, others merely lensed, and still others perhaps completely disintegrated. Those which occur in the border gneisses, which were certainly never in a magmatic condition, are interpreted as relatively unaffected portions of the country rock surrounded by granitized rock.

Aplites occur in the gneissic rocks, most abundantly in the granitic portion. Many are very irregular with rounded form and gradational boundaries, suggesting that replacement has been an important feature during their formation. A noteworthy feature of the aplites is the occurrence of foliation parallel to that of the coarse-grained gneiss, and therefore in most cases cross-cutting the aplite boundaries. This foliation must have been induced after solidification of the aplites and is definite evidence of deformation after the intrusive and its offshoots had cooled.

Much vein quartz is present; though much of it is barren, some veins carry pockets of microcline showing the same optical peculiarities as that in the aplites and in the granitic rocks.

PETROGRAPHY.

Rosiwal analyses of five specimens, whose locations are shown on the areal map (Fig. 2), are given here. H-4 and H-5 are part of a series across the intrusive margin and are described in detail under the section on Border Gneisses.

	H-1	H-2	H-3	H-4	H-5
Quartz	35%	33%	33%	39%	29%
Microcline	40	40	33	30	36
Plagioclase	15	20	28	27	29
Biotite	6	5	2	2	3
Muscovite	3	1	2	1	1
Epidote	2	rare	rare	rare	2

Accessory minerals, present in very small amounts, are: allanite, apatite, zircon; and opaque minerals, chiefly magnetite. Calcite and chlorite occur in scattered grains.

It will be noted that the composition of these specimens varies considerably, but all are within the granite range. The variation is not progressive so far as the present data goes, except for the fact that plagioclase—most of which is interpreted as a secondary or deuteric addition—is generally more abundant in the outer part of the intrusive, as shown by H-4 and H-5.

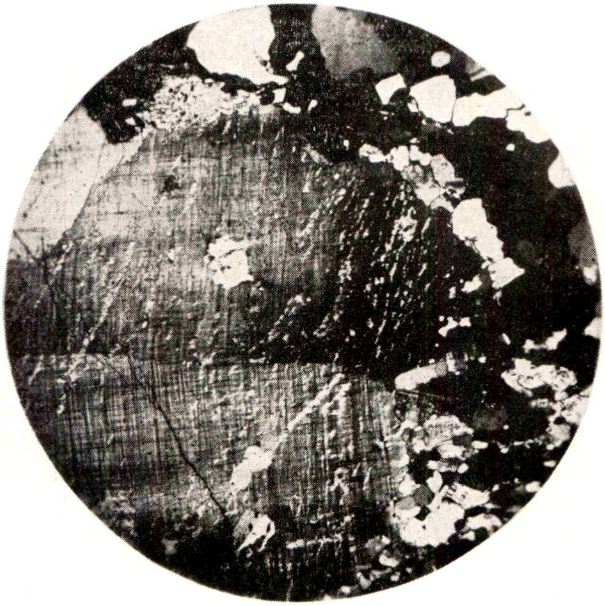

Fig. 4. Streaked microcline-perthite from granite, showing strain and corroded edges. Crossed nicols, x 30.

If contamination of the granite has occurred, as seems probable, it has then affected the composition irregularly. The occurrence of knots as abundantly in the center of the present exposure as near the margins shows that foreign material has spread through the whole intrusive at the level now visible.

Ten sections of the granitic rocks, from specimens scattered over the whole area, were studied. The following description refers to these sections.

Quartz forms a granular mosaic, and generally shows strain shadows. It occurs both in individual grains, and in large aggregates apparently formed by crushing of large single grains. These aggregates are commonly drawn out parallel to foliation.

The large grains of microcline are subhedral or anhedral, usually twinned on a fine scale, though many grains are untwinned. Some carlsbad twins show the grill twinning in one half but not in the other. Nearly all the microcline is perthitic. The included plagioclase occurs chiefly as vein-like aggregates forming an irregular perthite (Fig. 4) similar to the injection-perthite described by Colony.[7] Small quartz grains also occur as inclusions; in some cases at least these have been produced as a byproduct of replacement by plagioclase. In general microcline is entirely free from sericite or kaolin.

Measurement of optic angles with the universal stage shows that both twinned and untwinned grains have angles between 80° and 85°. The extinction angle $X \wedge 010$ on 001 is approximately 8°. The microcline in aplites and quartz veins shows the same properties. These data check neither for microcline nor anorthoclase.

Alling[8] and Winchell[9] have given graphs for optical determination of the feldspar series Or-Ab and Mi-Ab. The data given above approximate most nearly to a value of Mi_{70}-Ab_{30}; though the extinction angle is too low, and the optic angle too high for agreement. Accordingly, the mineral is considered to be a soda microcline.

The uneven development of twinning suggests that it is a strain effect rather than primary. The microcline could hardly have developed from orthoclase, however, since in that case we would expect that untwinned grains would have optical characters closer to those of orthoclase.

Plagioclase occurs partly in large irregular finely-twinned grains, of the order of size of the large microclines, but mostly in small irregular grains and in fine granular untwinned aggregates. The composition of both is acid oligoclase. The large grains are generally well altered to sericite and epidote, and show in places broken and bent lamellae; the fine granular material is in large part quite fresh.

The fine-grained plagioclase replaces microcline, which has a sutured margin indicating corrosion. In some cases this material is continuous with the plagioclase component of irregular perthites, showing that this type of perthite has been produced by replacement. Plagioclase also replaces quartz, and occurs in veinlets interstitial to and replacing grains of that material (Fig. 5).

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[7] Colony, R. J.: Final Consolidation Phenomena in the Crystallization of Igneous Rocks. Jour. Geol., Vol. 31, pp. 169-178, 1923.

[8] Alling, H. L.: Mineralography of the Feldspars, Pt. 1. Jour. Geol., Vol. 29, p. 231, 1921.

[9] Winchell, A. N.: Studies in the Feldspar Group. Jour. Geol., Vol. 33, p. 722, 1925.

The large twinned grains and the fine granular material have the same composition, within the limit of error of determination, as already stated. This suggests the possibility that both may have been produced at the same time, as replacement products. Evidence against this view, however, is afforded by the subhedral outline of many of the large plagioclase grains against microcline, and the very different microcline-plagioclase relations where replacement by plagioclase has certainly taken place. In these cases the result is a mottled aggregate of plagioclase and associated quartz blebs within the microcline, and often replacing it in blocky fashion, as shown by Fig. 6. For these reasons, the large twinned oligoclase, which makes up a very small amount of the total plagioclase, is considered to be a primary constituent, and the fine granular material to be a deuteric, or possibly secondary, addition.

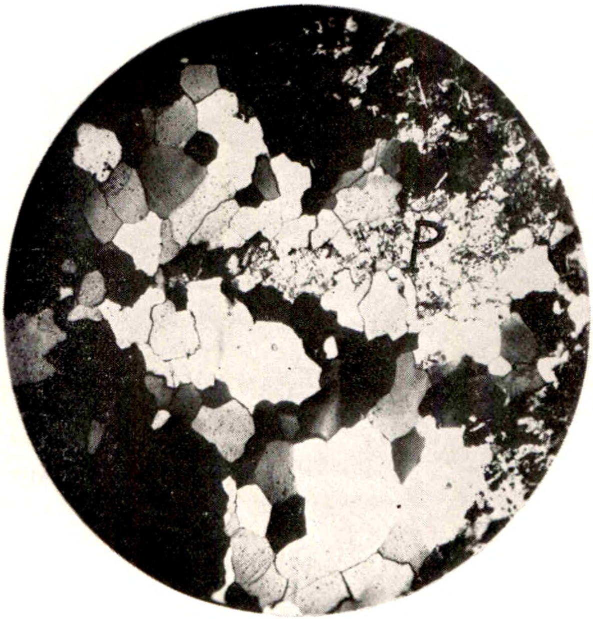

Fig. 5. Plagioclase vein (P) in primary quartz, from granite. Crossed nicols, x 30.

Biotite occurs in small strongly pleochroic flakes of dark olive-green color. It is usually segregated into patches or streaks, of which a thin section may contain only three or four. It shows no strain or bending; because of this it is considered to have recrystallized at some time after the last deformation. Muscovite is associated with biotite and apparently has had a similar history. Epidote occurs in rounded grains and also with subhedral or euhedral outline. It is partly an alteration product of plagioclase, but much of it seems to be added material, replacing chiefly quartz. The rare grains of allanite are surrounded by parallel growths of epidote, indicating contemporaneous formation of these two minerals.

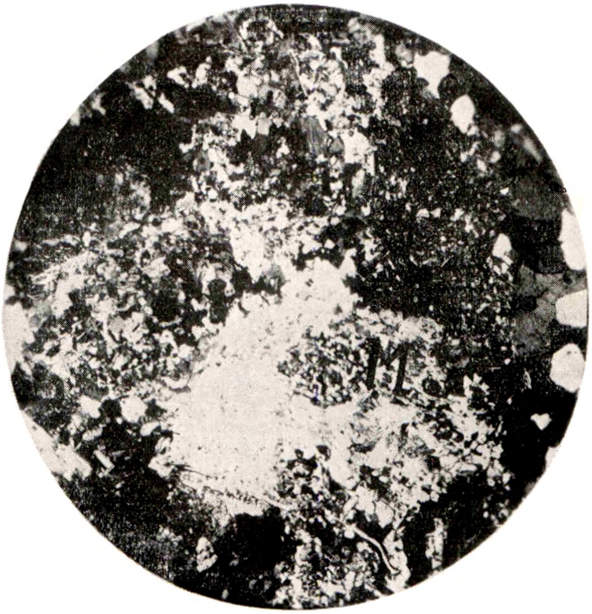

Fig. 6. Plagioclase (white, below center) flecked by included quartz blebs, and blocky replacement of microcline (M) by plagioclase. Crossed nicols, x 18.

DYNAMIC EFFECTS.

Most of the larger grains of microcline and plagioclase show strain, especially as indicated by a sweeping extinction. Some granulation has also occurred. The quartz is in general moderately strained, but its typically aggregated habit suggests that the aggregates were originally large grains which have undergone crushing.

The unstrained nature of biotite and muscovite contrasts with the obvious straining exhibited by certain large biotite crystalloblasts which occur in places in the schists, as described above, and which are interpreted as products of contact metamorphism. The biotite in the granitic rocks, and the oriented biotite in the schists, occurs bordering and thrusting into crushed quartz aggregates. The conclusion must be that this biotite in its present form post-dates at least the maximum cataclastic deformation, since it could not have remained untouched while granulation was occurring; and conversely, that quartz and feldspar were formed earlier than such deformation. The biotite may have taken its present form either during the closing stages of deformation, or at some later time. In the latter case the very definite orientation of the biotite, as brought out by fabric analysis (Fig. 11) must be merely an inherited orientation following the foliation planes determined by the other minerals.

IV.

BORDER GNEISSES: GENERAL.

The central granitic zone grades into a border of biotite-quartz gneiss, of variable composition and texture. The change from granite to border gneiss is not progressive; rather, quartz and feldspar content is irregularly variable. In general, however, there is an increase in biotite content, and in degree of visible foliation therefore, and a decrease in grain size, toward the outside of the gneissic area. This gradation is apparently without interruption.

Since there is no definite boundary between the border zone and the true granite; and especially since they seem to interfinger, they are not differentiated on the map, but are shown together as "granite gneiss and associated gneisses."

On the outer edge of the border gneiss the increasing biotite content and decreasing grain size cause an approach to the appearance of the adjoining quartz-biotite schist. The contact between border gneiss and schist is poorly exposed, but at several places it can be seen that the variation, instead of being completely gradational, is discontinuous; with a distinct contact between a type in which the biotite is segregated into streaks, as in the gneisses, and a type in which the biotite occurs in individual flakes scattered through the rock, as in the schists. The gneissic rock close to this contact contains ten per cent or more of feldspar, mostly or wholly sodic plagioclase; the schistose rocks are identical with the ordinary quartz-biotite schist and show only scattered feldspar grains. The change from gneissic (discontinuous) to schistose (continuous) structure, then, coincides in these places with a distinct drop in feldspar content.

In a few places, where exposures are abundant, there seems to be no such sharp break in structure. Notably in the bed of Mink Brook, in the town of Etna on the east side of the area, gneissic rocks, in the above use of the term, grade into schistose rocks with no sudden change visible in exposures. Thin sections of rocks in this area show that microcline as well as an abundance of fine-granular plagioclase is present in the gneissic rocks; while in the schistose rocks to the east only the fine plagioclase, replacing quartz, occurs. More detailed study would reveal the outer limit of plagioclase addition here.

PETROGRAPHY.

To show the way in which composition varies along a traverse from the granitic rock through the border gneiss, Rosiwal analyses are given of a series of four specimens from Crafts Hill, in the southwest part of the area. Their location is indicated on the map, Figure 2. H-8, from the border zone in the northern part of the area, is given to show some additional features.

	H-4	H-5	H-6	H-7	H-8
Quartz	39%	29%	41%	33%	25%
Microcline	27	36	6	..	..
Oligoclase	27	29	25	7	30
Andesine	..	..	2	3	..
Biotite	2	3	21	25	27
Muscovite	1	1	1	1	3
Hornblende	..	..	..	22	..
Epidote	rare	2	3	9	15

The suite H-4, 5, 6, and 7 was collected at nearly equal intervals in a distance of slightly less than a half-mile across the strike of the border zone boundary. H-4 and H-5 are typical light-colored granites with porphyritic microcline and with obscure foliation due to the small amount of biotite. The biotite, however, is well oriented; see biotite orientation diagram of H-5 (Fig. 11). H-6 is somewhat finer in grain, with distinctly discontinuous foliation still. H-7 is still finer grained, and dark colored due to the large proportion of biotite and hornblende; its foliation is discontinuous though less so than that of H-6.

Under the microscope, H-4 is similar to the granites already described. H-5 differs from H-4 in the greater abundance of fine-granular untwinned plagioclase, and in greater degree of replacement of microcline. A coarse myrmekite-like mixture of quartz and plagioclase has been produced in places by nearly complete replacement of microcline. Plagioclase masses have irregular sutured boundaries against microcline and form granular veins within it. These textures are similar to the 'pseudo-cataclastic' texture described by Anderson[10] and explained by him as the result of albitization. Many of the large microcline grains are bordered by small grains of well-twinned microcline, indicating that actual cataclastic deformation has taken place also in these rocks.

The structure of H-6 and H-7, on the other hand, is quite different. In both the quartz occurs commonly in band suggestive of sedimentary banding seen in normal schists of this area. Plagioclase forms vein-like stringers between these bands, and occurs also in larger aggregates and in large mottled grains. Nearly all this plagioclase is untwinned. It definitely replaces quartz, and is obviously an addition to the rock rather than a primary constituent.

A few small fresh well-twinned plagioclase grains are scattered through the rock. The twinning follows the pericline rule alone (or possibly one of the rarer twins with 001 composition face); albite twinning is never present. No cleavage could be found to allow determination of extinction angles; index determination indicates that this feldspar is definitely more calcic than the oligoclase and that it falls in the andesine range.

Slide H-8, from the outer part of the border zone in the northern part of the area, contains 30 per cent feldspar, of which two-thirds is made up of coarse grains of subhedral well-twinned oligoclase. The remainder is fine-granular material that has replaced quartz. No microcline is present. The coarse-grained oligoclase is strongly epidotized; because of this and the distinct difference in habit as compared with the fine-granular material, it is considered to have been a true contact-metamorphic product.

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[10] Anderson, G. H.: Pseudo-cataclastic Texture of Replacement Origin in Igneous Rocks. Am. Min., Vol. 19, pp. 185-193, 1935.

A point brought out by this slide is the absence of the fine-grained plagioclase with pericline twinning, which occurs in H-6 and H-7, and which was there identified as andesine. Examination of slides of other border zone rocks brings out the fact that this mineral is commonly present and is locally abundant in the rocks along the western and northwestern border of the intrusive, and conversely that it is rare and generally absent on the east and southeast border.

The fact that the andesine has more lime than does the oligoclase, and that it has pericline twinning without albite twinning, while the oligoclase is nearly devoid of any twinning, indicates that the andesine was formed under a distinctly different set of conditions. The most probable explanation of what these conditions were, is that the andesine formed during regional metamorphism, which followed intrusion and albitization.

That so much of the oligoclase was unchanged suggests that its stability range was only slightly exceeded. Explanation of the restriction of the andesine to the western boundary of the intrusive is, however, probably to be found in the relative abundance of lime, now chiefly present in hornblende and calcite, in the rocks of this area. During metamorphism this lime would become active and would be expected to have some effect on nearby metamorphic products.

Several workers have shown that the lime-content in the form of plagioclase that is stable under any given metamorphic conditions increases as the grade of metamorphism increases.[11, 12] Harker points out that production of the more calcic plagioclase during advancing grade of metamorphism depends also on available lime[13]; this appears to have been the determining factor in the present case.

There also arises the question of whether the oligoclase represents the original replacing material, or whether it also has gained lime during metamorphism. The restriction of its present composition to the sodic oligoclase range, and the contrast in composition and twinning with the andesine, suggest that it is the original material.

[11] Phillips. F. C.: Mineralogical and Chemical Changes Induced by Progressive Metamorphism in the Green Bed Group of the Scottish Dalradian. Mineral. Mag., Vol. 22. pp. 239-256. 1930.

[12] Turner. F. J.: Genesis of Oligoclase in Certain Schists. Geol. Mag., Vol. 70, pp. 529-541. 1933.

[13] Harker, A.: Metamorphism. London, pp. 93-94, 1932.

In the granite of replacement origin described by Gilluly the replacing albite is "at least as sodic as $Ab_{90}An_{10}$ and much of it is probably more sodic."[14] Sederholm states that the plagioclase in myrmekite, which he interprets as chiefly a deuteric effect, is commonly of the series oligoclase-albite.[15] Fenner applies the change in composition of stable plagioclase with change in grade of metamorphism to show that a deuteric plagioclase is not necessarily nearly pure albite, but may contain appreciable amounts of lime.[16]

ORIGIN OF BORDER ZONE.

The border zone gneisses show in the field a banded structure which is similar to the sedimentary banding in the schists. More importantly, microscopic study reveals that their composition approaches that of the schists, especially in biotite and quartz content; and that feldspar, which is chiefly fine-granular plagioclase, is an added material, replacing quartz. These factors rule out the possibility that the border zone rocks are of igneous origin, intruded into their present position. They represent, on the contrary, quartzose sedimentary material to which has been added varying amounts of feldspar and possibly other material, and on which has been imposed a gneissic texture at some time during this addition. The addition of microcline and some plagioclase during the intrusion of the nearby granite may be termed granitization, while the later addition of plagioclase, after solidification of the granite (since the granite itself is replaced by this material) is commonly known as albitization.

V.

METAMORPHISM—SUMMARY.

According to the evidence presented, the following series of events occurred in this area: intrusion of granite, production of border gneisses, and regional metamorphism. This sequence will be discussed and elaborated.

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[14] Gilluly, J.: Replacement Origin of Albite Granite, Oregon. U. S. G. S. Prof. Paper 175C, p. 69, 1933.

[15] Sederholm, J. J.: On Synantetic Minerals and Related Phenomena. Comm. Geol. Finlande, Bull. 48, 1916.

[16] Fenner, C. N.: Residual Liquids of Crystallizing Magmas. Mineral. Mag., Vol. 22, pp. 539-560, 1931.

No inference can be made from present data as to the condition of the sedimentary rocks prior to the intrusion.

The contact effects of the intrusion itself are to be separated from the albitization, although this probably occurred in the final stages of cooling. Addition of microcline to the border rocks was undoubtedly a contact effect. Also, by analogy with the primary plagioclase in the granites, the coarse well-twinned oligoclase in the border rocks is considered a contact product. Scattered biotite crystalloblasts cross-cutting the present foliation are interpreted as probable contact products. The kyanite that occurs on the east side of the area may also date originally from this time. The rare sulphides are presumably related to the intrusive; their age relative to albitization is unknown.

No other effect can be definitely referred to the intrusive period. Hornblende, garnet, and the ordinary foliating biotite have no apparent zonal relation to the intrusive; if part of their material was added to the country rock from this intrusive, it was done in very irregular and far-reaching fashion. It may be that this granite was part of a large-scale intrusive series, and that accompanying regional addition of bases, especially Ca, Mg, and Fe, took place in the manner suggested by Currier.[17] The large amount of hornblende present in places is possibly due to such regional metasomatism.

Following consolidation of the granite,—probably closely following it—, albitization, (if we may use that term when the plagioclase is not strictly albite) took place, spatially restricted largely to the margins of the granite, but also affecting the granite itself. The large-scale formation of epidote is similar to that of oligoclase except that epidote is much more widely distributed. It is, however, most abundant in the border gneisses and nearby schists. This point, as well as the intimate association of epidote with allanite, suggests that the epidote was also largely a deuteric addition.

At a later time regional metamorphism accompanied folding, and affected some recrystallization and granulation of minerals. Foliation was produced, partly by drawing out of crushed mineral aggregates, partly by the production of shear planes which were followed by biotite and hornblende during a later recrystallization. A small amount of andesine was produced, presumably where lime-bearing solutions were active. Garnet and kyanite probably date from this stage.

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[17] Currier, L. W.: Regional Granitization and Metamorphism in New England. (abstract), Am. Min., Vol. 22, No. 12, Pt. 2, p. 3, 1937.

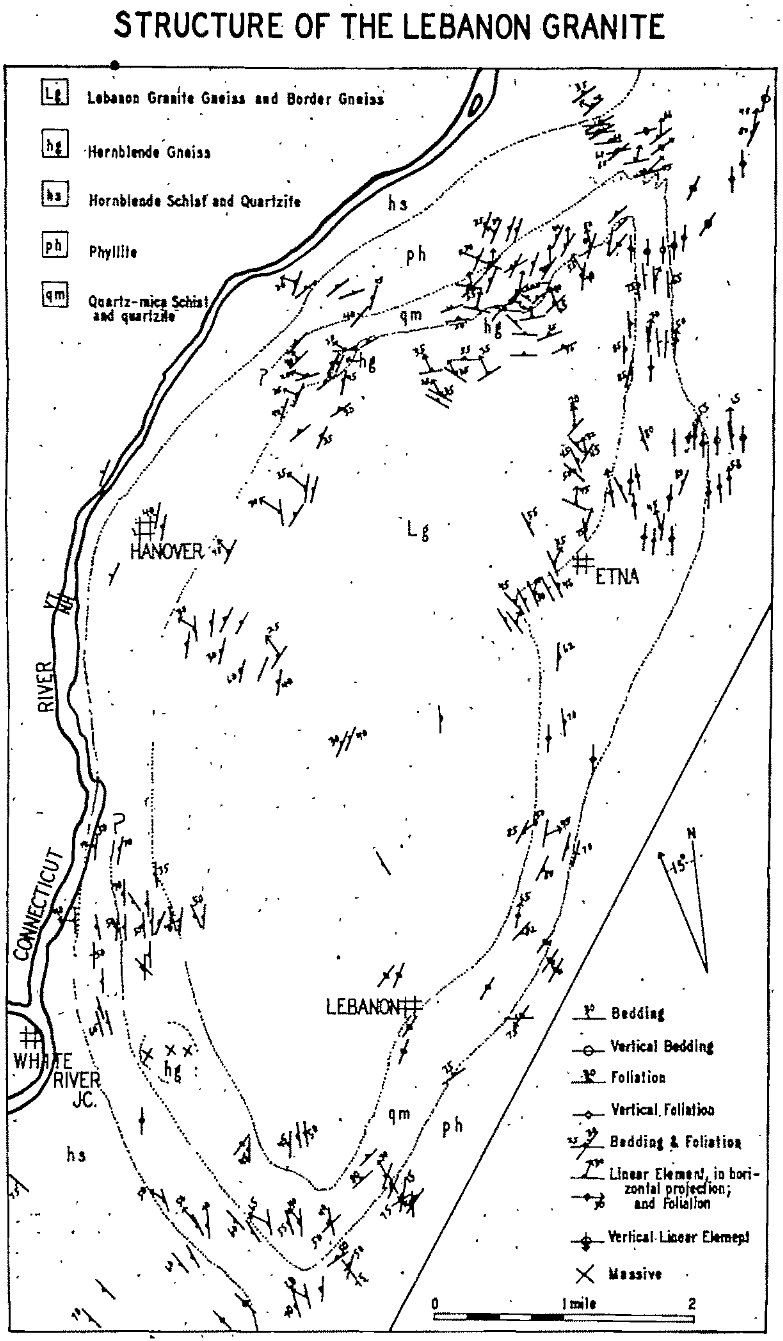

Fig. 7. Structural map of Lebanon Granite and nearby rocks.

Finally, biotite was recrystallized at some later stage to produce the unstrained flakes now present. This may have occurred during the declining stages of regional metamorphism, or at some later time when stress was absent.

VI.

STRUCTURAL: GENERAL RELATIONS.

The structural trend in central New Hampshire is north-northeastward, and structural axes plunge generally northward. This pattern is followed by the structure of the present area. Detailed analysis of structural features will be given.

As the map (Fig. 7) shows, the intrusive is distinctly elongated in a northeasterly direction, and is surrounded by schist bands that are wrapped around it and which conform generally to its outline. The pattern of these schist bands is a very simple one except at the extreme north and south ends of the oval outcrop area. In these two localities the schists are contorted into isoclinal folds of all sizes. Drag folds are commonly present in all the schistose rocks of the area. Jointing is irregularly developed; the only observable relation to other structures is the parallelism of one joint set to northeast-trending faults outside the area here considered. Aplite dikes are extremely irregular, even in a single outcrop, and follow no recognizable pattern.

PRIMARY STRUCTURES.

The knots that occur in the gneisses have good planar orientation. Those in the granite must represent a primary igneous flow structure. As mentioned before, knots occur in the quartz-rich border gneisses which represent granitized sediments and which were never in a liquid state. These knots are interpreted as 'islands' of original material in a generally granitized rock; their orientation is therefore a remnant of earlier, probably sedimentary structures.

Microcline phenocrysts are approximately equidimensional except where crushed, and have no apparent orientation. In view of the crushing of quartz which has been produced by deformation, it seems to the writer that orientation of elongated quartz aggregates is a doubtful primary structure, and that such elongation may simply be a result of the deformation itself.

Bedding is recognisable in most of the schists of the area. Banding in the border gneisses is in many cases also an expression of original sedimentary variations.

FOLIATION.

Foliation is present in nearly all the rocks of the area: the exceptions are the late lamprophyre dikes; portions of the hornblende gneisses; and some extremely biotite-poor parts of the granite. In the latter case absence of foliation is probably due merely to lack of sufficient biotite to make it visible. In the hornblende-rich rocks, bending of feldspar lamellae indicates that the rocks antedated the last deformation. Absence of foliation must mean then that haphazard recrystallization of hornblende has occurred since then.

In the schists, foliation is usually nearly parallel to bedding. Even in the isoclinal folds as well as in the drag folds, foliation in most cases bends around the noses of the folds. Foliation in the gneisses is accordant with that in the schists; no sudden change across contacts is seen in the field or in the plotted data on the map.

In most cases the knots and schlieren are parallel to the foliation though small angular differences are not uncommon. Aplites are foliated parallel to the general gneissic foliation.

Distinct lineation is generally present in both schists and gneisses, and is produced by orientation of hornblende rods and of elongated mica flakes within the foliation. Its changes in direction, like those of foliation, show no discontinuity across rock boundaries. The general trend of the lineation is steeply plunging to the north-northwest; its position is shown by the full arrows on the map (Fig. 7). Lineation is parallel to axes of drag folds and of isoclinal folds. This observation is in accord with those made by many workers in other areas, and shows that lineation bears a definite relation to the stresses that produced folding in the schists and foliation in both schists and gneisses.

FABRIC DIAGRAMS.

Orientation diagrams were made of three specimens: H-5 (Fig. 8), a member of the border gneiss suite described above, is a typical coarse-grained granite gneiss poor in biotite; H-9 (Fig. 9) is a biotite-quartz gneiss from the outer border zone on the east side of the area; and H-10 (Fig. 10) is a hornblende gneiss from the border zone northeast of Hanover. For location of these specimens see areal map, Fig. 2. H-10 contains considerable plagioclase and may have been affected by a basic intrusive of the type described above (See page 113).

The thin sections were cut normal to the megascopic lineation, B; and the diagrams were rotated into the position shown, in which the projection plane is normal to *a* (an imaginary line, in the foliation plane and normal to *B*). As usual the projection is of the equal-area type.

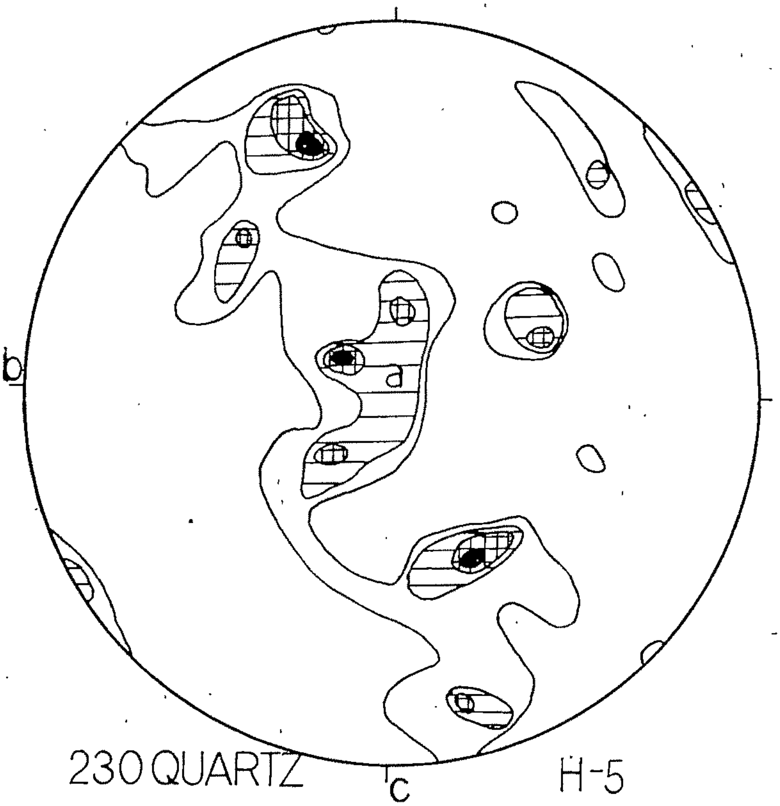

Fig. 8. Contours are 4, 3, 2½, and 2%.

All three quartz diagrams show girdles about the lineation *B*, and point maxima within the girdle. Maxima are three or four per cent, which is the usual intensity found in rocks of this type. The biotite diagram of H-5 (Fig. 11) shows the very definite orientation of the biotite, and a symmetrical partial girdle normal to *B*. These rocks then are tectonites, and according to the usual interpretation[18] of such diagrams have undergone deformation partly by intergranular rotation, to produce the girdle, and partly by shear, to produce the point maxima.

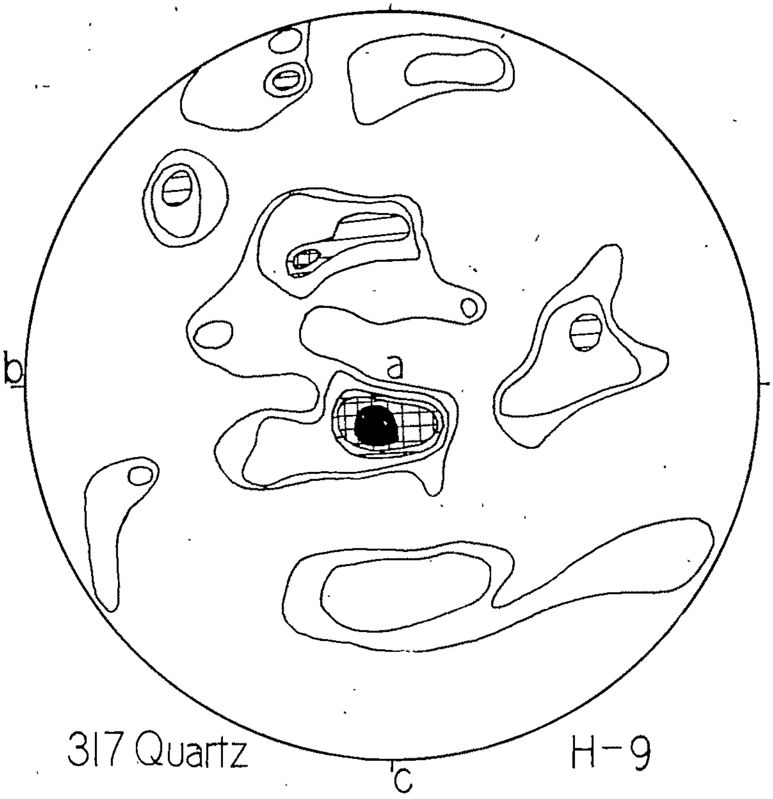

Fig. 9. Contours are 4, 3, 2½, 2, and 1%.

The three quartz diagrams agree most notably in showing a strong maximum in or very near *a*. They also agree in lack of symmetry about *B*, of such a type that rotation of the girdles about the axis *a* is necessary to make them normal to *B*. Diagrams of H-5 and H-10 (Figs. 8 and 10) show some evidence of the development of two girdles intersecting in the *a*-axis, and nearly symmetrical about the *ac* plane. In both diagrams, however, one girdle is much stronger than the other.

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[18] Fairbairn, H. W.: Structural Petrology. Queen's University, Kingston, Ontario, 1937.

Similar asymmetrical diagrams have been described, especially from areas of 'granulite,' in Saxony,[19] Greenland,[20] Lapland,[21] Switzerland,[22] and southern Quebec.[23] The term granulite is used to include medium or coarse-grained metamorphic rocks composed chiefly of interlocking granular

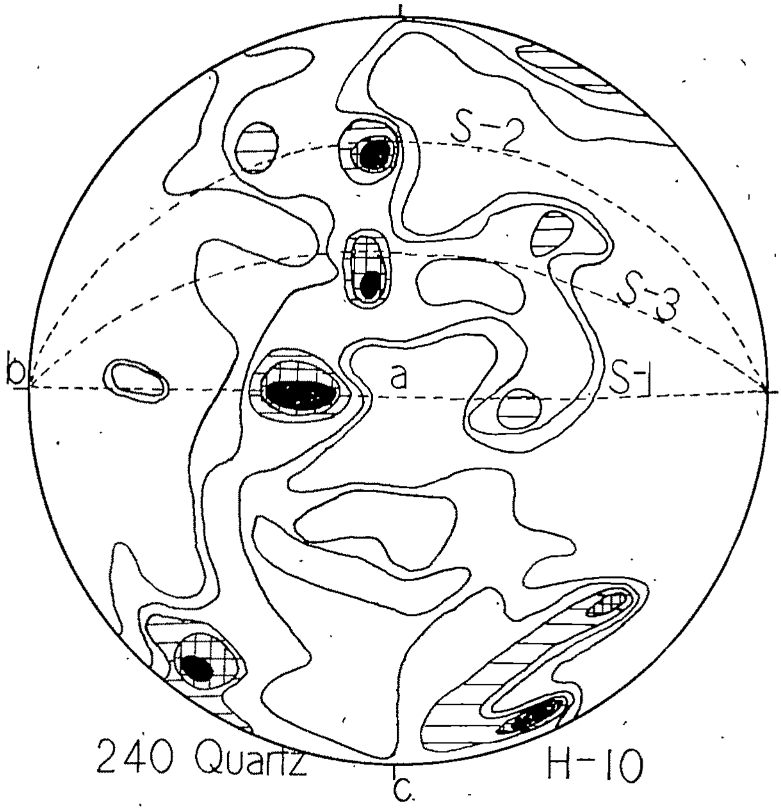

Fig. 10. Contours are 4, 3, 2½, and 2%.

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[19] Seng, H.: Die Gefügeeigenschaften von Granuliten. Min. Petr. Mitt., Bd. 41, pp. 353-472, 1931.

[20] Sahlstein, T. G.: Zur Regelung der Gesteine im Kristallin des Liverpool Landes in Ostgrönland. Kommiss. Vidensk. Undersøgelser Grønland, Bd. 95, 1935.

[21] Sahlstein, T. G.: Die Regelung von Quarz und Glimmer in den Gesteine der Finnisch-Lapplandischen Granulitformation. Comm. Geol. Finlande, Bull. 113, 1936.

[22] Closs, H.: Quarzgefügestudien im östlichen Graubünden. Min. Petr. Mitt., Bd. 46, 1935.

[23] Osborne, F. F., and Lowther, C. K.: Petrotectonics at Shawinigan Falls, Quebec. Bull. Geol. Soc. Am., Vol. 47, pp. 1343-1370, 1936.

minerals. Since the rocks under present discussion are composed chiefly of quartz and feldspar, they fall within this class, as separated from a class of rocks composed chiefly of platy minerals.

These writers conclude that where quartz and biotite diagrams do not agree, the biotite defines the major deformation, whereas the quartz has been affected by a later deformation too weak to rearrange the whole structure of the rock. Thus even if the biotite was later recrystallized, it follows the major s-planes produced by the earlier deformation and gives no evidence of the later one. Unless orientation of a glide line in the biotite cleavage can be shown to be present, the biotite is considered to have taken no part in the deformation but to have a purely imitative orientation.

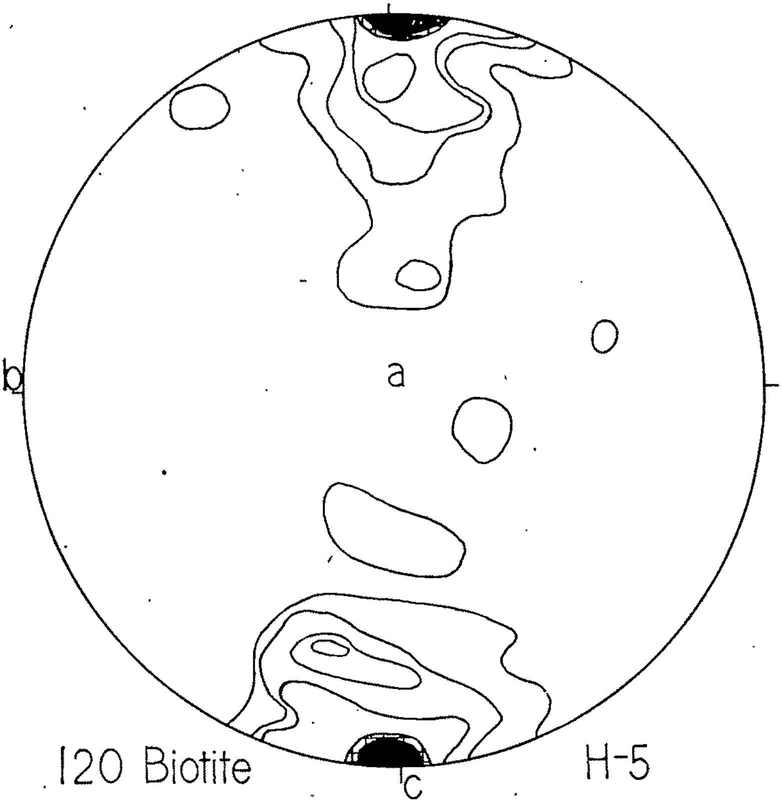

Fig. 11. Contours are 10, 8, 6, 4, and 2%.

The rocks in the present area show in most cases strong lineation. The lineation defined by the biotite girdle coincides (except in a few special cases to be noted below) with the megascopic lineation, and this in turn is parallel to axes of folds. Hence there is no doubt that this lineation was produced or controlled by the major deformation suffered by these rocks; and therefore that the biotite, even if recrystallized later than the deformation, has followed the major s-planes in the rocks. If a later deformation has occurred to modify the quartz orientation, it has left no sign in the major fold or drag fold patterns. The alternative explanation, that the quartz has retained the effects of an earlier deformation whose megascopic features have nearly or wholly disappeared, has been discounted by all the workers cited.

ROCKS WITH TWO CLEAVAGES.

In several instances two distinct cleavages were noted, especially in the crumpled schists at the ends of the intrusive; several such occurrences are recorded on the structural map as two foliation symbols superposed. Both cleavages are produced by mineral orientation, of both hornblende and mica, and therefore are flow cleavages rather than fracture cleavages, according to the usage of C. K. Leith. In most cases, lineation is parallel to the intersection of the two surfaces. This circumstance indicates more than a chance relation between them.

Specimen H-10 exhibits two such cleavages. Matching of these with the quartz orientation diagram brings out the point that the strong maximum in *a* coincides with the best cleavage (shown as S-1 in diagram, Fig. 10). A weaker maximum in the girdle, about 40° from *c*, coincides with the other cleavage (S-2 in diagram). A third maximum between these two lies in the plane of the visible foliation (S-3). The maximum in *a* corresponds to Sander's Maximum I, the maximum in the other cleavage to Maximum II. These maxima and cleavages presumably represent the most important s-surfaces in the rock, intersecting in B. Whether they were produced at the same time cannot be shown by the evidence at hand.

It may be mentioned that preliminary work on a fine-grained two-cleavage schist indicates a quartz statistical *b*-axis (defined by a girdle) at an angle to the megascopic *B*-axis. This suggests that two deformations have affected the rock, or at least that the direction of applied stress was shifted.

SECONDARY PRODUCTION OF FOLIATION.

The chief field evidence that the foliation and lineation in this area are secondary and produced by dynamic metamorphism is the fact that aplites are foliated parallel to the regional foliation. The fact that lineation is parallel to axes of folds in the schists is contributory evidence, since lineation and foliation are obviously related. Finally, the evidence of orientation diagrams indicates typical tectonite orientation of the constituents of the rocks.

CONTROL OF FOLIATION.

It has been pointed out that schlieren and especially knots are in most cases parallel to foliation. Whether the long axes of knots are parallel to lineation could not be proved. Since this orientation defines an original flow structure, it is evident that foliation has followed flow structure in general. In the border gneisses, foliation is generally parallel to banding, which is undoubtedly an expression of original sedimentary bedding.

It follows from these relations that foliation generally parallels the outline of the intrusive, as the map shows. The only large-scale exception occurs near Etna, on the east side of the area. As the map indicates, the gneiss boundary bulges to the west at Etna, and then swings to the east just north of Etna. This irregularity is not due merely to uneven border gneiss production, but is followed by the intrusive itself, as shown by the occurrence of granitic rocks north of Etna and in the belt from there to the northeast end of the gneissic area. The foliation near Etna swings to the northwest and so cuts directly across this contact. The general orientation of knots here is not known because of poor exposures. It is possible that flow structure forms an arch around to the west here, and that foliation partly followed it. More probably, however, the deforming stress produced a foliation that cuts across the earlier structures because of their sudden change in direction.

FORM OF INTRUSIVE.

Since foliation is generally parallel to the outline of the intrusive, its attitude can be taken as approximately that of the intrusive boundary, in a vertical as well as horizontal sense. Lineation is parallel to axes of folds; it seems probable that folds developing around a resistant massif such as this would form with their axes parallel to the long axis of the massif. Since lineation plunges generally northwestward, the massif itself is inferred to plunge in the same direction.

The border schists, if reconstructed above the present erosion level, would close not far above the present surface, which is probably therefore fairly near the original top of the intrusive.

The elongated plan, plunging axis parallel to regional fold axes, and concordant relations of the intrusive mass suggest a phacolithic structure. Detailed field work in the schists near the southern end of the area left the writer undecided as to whether the schist bands wrap around the end of the massif or swing away from it.

In any case, the elongation parallel to regional structure, the sharply arched schist pattern, and the wide zone of border effects indicate intrusion into folded rocks under considerable heat and pressure, allowing slow cooling and retention of late-magmatic juices. But it has been shown that intrusion antedated the last major folding by a space of time enough to allow injection and cooling of aplites before that folding. According to Billings,[24] the last regional deformation was late Paleozoic, either late Devonian or late Carboniferous. As the Ordovician folding is considered by Billings to have had a relatively slight effect in this region, it is probable that the Lebanon granite was intruded during the early stages of the late Paleozoic orogeny.

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[24] Billings, M. P.: Geology of the Littleton and Moosilauke Quadrangles, Concord, N. H., p, 42, 1935.

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AGE OF THE "LOS ANGELES MAN" DEPOSITS.

THOMAS CLEMENTS.

ABSTRACT.

Human and elephant remains were found during excavation for a storm drain near Los Angeles, California, in 1936. The deposits in which the remains occurred are flat-lying river beds that have been uplifted and are being dissected by a small stream. They rest unconformably upon tilted marine strata containing a lower Pleistocene invertebrate fauna.

The uplift and tilting of the marine beds is believed to have taken place at the time of the Pasadenan orogeny (middle Pleistocene). The later uplift that inaugurated the present dissection of the river beds is correlated with the break between Pleistocene and Recent. It is the opinion of the writer that the deposits containing the remains were laid down by the stream that beveled the lower Pleistocene marine sediments, and are late Pleistocene in age. They are the probable equivalents of the Rancho La Brea and Centinela Park deposits.

The finding of human and other mammalian remains during the excavation for a storm drain near Los Angeles, California, was reported late in 1936.[1] The age of the deposits containing the remains is given as Pleistocene on the basis of the verbal statement of the present writer. A brief account of the reasons for the statement was presented before the Cordilleran Section of the Geological Society of America early in 1937.[2] It is the desire of the author at this time to set forth in detail the observed facts upon which the determination of age was based, in order that other workers in the field may be able to judge the validity of the opinion.

The author was not on the site when the remains were found, nor did he visit it until some weeks after the material had been removed, by which time the conduit was being constructed and the ditch had been partly back-filled. However, both Doctor Bowden and Doctor Lopatin are recognized as competent workers, and there is no apparent reason for doubting that the human and other bones came from the localities designated by them.

The line of the storm drain in question runs in an east-west direction across a gently sloping surface lying north of the Baldwin Hills between the town of Inglewood and a part of the city of Los Angeles. The ditch is parallel with and somewhat south of the Haverty sewer-trench, with which it has many features in common, and from which human and other vertebrates were taken during excavation in 1924.[8] The surface, called the Ballona Plain, drains to the west into Ballona Creek, which has incised its channel to a depth of approximately twenty-five feet below the general level of the plain, and shows the characteristics of a rejuvenated, formerly weakly-meandering stream.

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[1] Bowden, A. O., and Lopatin, I. A.: Pleistocene man in southern California, Science, Vol. 84, pp. 507-508, 1936.

[2] Clements, T.: Age of the "Los Angeles man" deposits (abstract), Proc. Geol. Soc. Amer. for 1936, p. 338, 1937.

At the time of the visit by the writer some fifteen feet of strata were exposed in that part of the ditch indicated as the site at which discovery of the human remains had been made. These were flat-lying, poorly defined beds of sandy clay, with which was interbedded a distinct stratum of gravel. None of the material was consolidated. The remains were said to have come from just above the gravel bed, at a depth of about thirteen feet. The sediments are unquestionably of river origin.

Approximately eleven hundred feet east of the above-described site, and at a depth of about twelve feet below the surface, which here is perhaps two feet higher in elevation than at the first site, were found four teeth and some fragments of bone in a bed of gravel. These were classified by the writer as belonging to the imperial elephant, *Archidiskodon imperator* (Leidy), on the basis of comparison with similar material from Rancho La Brea and Centinela Park. The gravel in which the remains occurred was overlain by a few feet of sandy clay, above which was a thin bed of peat covered with several feet of topsoil.

An attempt was made to trace the beds along the ditch between the two localities, but the regular sequence was interrupted, the sandy clay beds being replaced laterally for some little distance by gravels having no perceptible stratification. The workmen on the ditch spoke of this interruption as a "fault," but in view of the lack of any evidence of faulting, and the fact that the gravels are typically fluviatile, it is the opinion of the writer that they are simply the result of the well-known lateral variation of river deposits. It is possible that the gravels represent the entrance at that point of a tributary to the ancient stream that deposited the sediments as a whole.

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[8] Stock, Chester: A recent discovery of ancient human remains in Los Angeles, California, Science, Vol. 60, pp. 2-5, 1924.
Tieje, A. J.: The Pliocene and Pleistocene history of the Baldwin Hills, Los Angeles County, California, Bull. Am. Assoc. Pet. Geol., Vol. 10, pp. 502-512, 1926.

The strata at the two localities are not exactly identical in sequence, but they are decidedly similar, and there is nothing to indicate that they were not deposited by the same river at almost the same time. There seems, therefore, to be no valid reason for believing the beds at the elephant locality to be other than the approximate correlatives of those where the human remains were found.

In deepening the ditch at the site of the finding of the elephant material, it was disclosed that the flat-lying river beds truncated a series of easterly-dipping, poorly consolidated marine sediments yielding a rather abundant invertebrate fauna, both megascopic and microscopic. The *Foraminifera* were examined by Mr. Herschel Driver of the Standard Oil Company of California, who stated that they were largely forms of wide range, from Pliocene to Recent, but in all probability represented Pleistocene.[4]

Dr. A. J. Tieje of the University of Southern California examined the megafossils, identifying the following:

- Pelecypods
  - *Cardita ventricosa* Gould
  - *Pecten* aff. *(Patinopecten) caurinus* Gould
  - *Pecten hastatus* Sowerby
  - *Venus (Chione) undatella* Sowerby
  - *Solen sicarius* Gould
  - *Cryptomya californica* (Conrad)
- Gastropods
  - *Polinices (Euspira) lewisii* (Gould)
  - *Polinices (Neverita) recluzianus* (Deshayes)
  - *Turritella cooperi* Carpenter
  - *Crepidula princeps* Conrad
  - *Crepidula onyx* Sowerby

He says: "The age of the beds is not easily determinable. Although it might be Timms Point (regarded by Tieje as Pleistocene), at least nineteen characteristic and reasonably common to abundant markers of Timms Point are lacking. It can hardly be Palos Verdes, for all the more characteristic markers are lacking. Accordingly, the beds are located by the writer (Tieje) somewhere within the San Pedro (*sensu*

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[4] Personal communication.

stricto) formation. The fauna has a suggestion of one that preferred water colder than that at present off Los Angeles."[5] San Pedro (*sensu stricto*) is Arnold's lower San Pedro, which is considered to be early Pleistocene in age.

There is offered an interesting combination of possibilities for correlation: human and other vertebrates; large and small invertebrates, and physical evidence. The invertebrates establish the age of the underlying marine sediments as probable early Pleistocene and thus give a lower limit to the age of the flat-lying river beds. Between the time of deposition of the marine beds and that of the river beds, the former were uplifted, folded and eroded. This diastrophism may be correlated with the last major orogenic movement in California, the Pasadenan orogeny, which is dated as approximately middle Pleistocene.[6]

The flat-lying beds overlying the marine strata were probably deposited by the stream that beveled the latter. With them were deposited the human and the elephant remains. The possibility must not be overlooked that these might be reworked materials; exhumed by the river from an older deposit and reburied by it, since Tieje reports ground sloth remains from fresh-water beds apparently also truncated by the river gravels.[7] Such beds, however, were not observed in that part of the trench examined by the writer. There also is the possibility that either one may have been reworked and the other not. At any rate, neither can be considered as younger than the river beds, which makes the age of the latter of considerable significance.

These river beds at the present time are undergoing dissection by a stream of small size whose somewhat poorly defined meanders are entrenched to a depth of twenty-five or more feet below the surface of the so-called Ballona Plain. This indicates uplift following deposition of the river sediments, and it seems logical to consider this disturbance as marking the break between Pleistocene and Recent.

The river beds in which the human and elephant bones occur must therefore be post-Pasadenan and pre-Recent: in other words, late Pleistocene in age. In view of the fact that other Pleistocene vertebrate remains were found in these beds during the digging of earlier sewers,[8] the above suggested possibility of reworking seems improbable. Furthermore, the Centinela Park deposits are similar in character and contain the same elephant form, the fauna as a whole being comparable with that of Rancho La Brea,[9] which is generally accepted as being late Pleistocene.

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[5] Personal communication.

[6] Reed, R. D., and Hollister, J. S.; Structural evolution of southern California, p. 49, Am. Assoc. Pet. Geol., Tulsa, Okla., 1936.

[7] Tieje, A. J.: *op. cit.*, p. 505.

The evidence seems to establish definitely the age of the deposits as late Pleistocene. It is difficult to conceive of the human remains as being other than the same in age.

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[8] Stock, Chester: *op. cit.*, pp. 2-3.
Tieje, A. J.: *op. cit.*, p. 512.

[9] Clements, T.: A new Pleistocene vertebrate locality in southern California (abstract), Proc. Geol. Soc. Amer. for 1936, p. 298, 1937.

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A SUGGESTED EXPLANATION OF THE CURVATURE OF COLUMNAR JOINTS IN VOLCANIC NECKS.[1]

CHARLES B. HUNT.

ABSTRACT.

In a cooling volcanic pipe the columnar joints that first form are at the surface and stand in a vertical position. Such joints extend themselves downward into the less cooled portions of the pipe by stresses that are insufficient to open new cracks.

The heat loss in a vertical direction from a pipe diminishes with depth, whereas the heat loss laterally diminishes inward from the sides. From an analysis of the contraction stress ratios and of the incipient fractures dependent on the variable rates of cooling it is found that the incipient fractures progressively change from a practically vertical position at the top of a pipe to a practically horizontal position at depth. At any given point fracturing may be along either of two sets of planes, one dipping outward toward the sides of the pipe, the other dipping inward. The set dipping outward is favored by cracks extending downward from the surface because contraction is greater toward the sides than toward the center of the pipe.

Two conditions are essential for the development of columnar joints as a result of contraction due to cooling of a solid rock:

1. The contraction must overcome the tensile strength of the rock.
2. There must be centers of contraction at more or less equally spaced intervals on cooling surfaces within the rock.

Under these conditions, columnar joints tend to orient themselves normal to the directions of greatest tensile stress,—that is, normal to the lines connecting the centers of contraction and therefore also normal to the cooling surfaces and to the isotherms.

During cooling of a volcanic pipe the isotherms rise steeply along the sides of the pipe and flatten across its top. They are, therefore, convex upward. Since columnar joints generally develop normal to the cooling surfaces, it would seem that the joint columns in a volcanic neck should converge downward. The fact is that they do just the reverse (Fig. 1).

The mechanics of the columnar joint development in basaltic volcanic rocks have, for the most part, been analyzed and explained satisfactorily in geologic literature. But, so far as I am aware, no attempt has been made to explain the mechanical factors that control the characteristic curving of columnar

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[1] Published by permission of Director, United States Geological Survey.

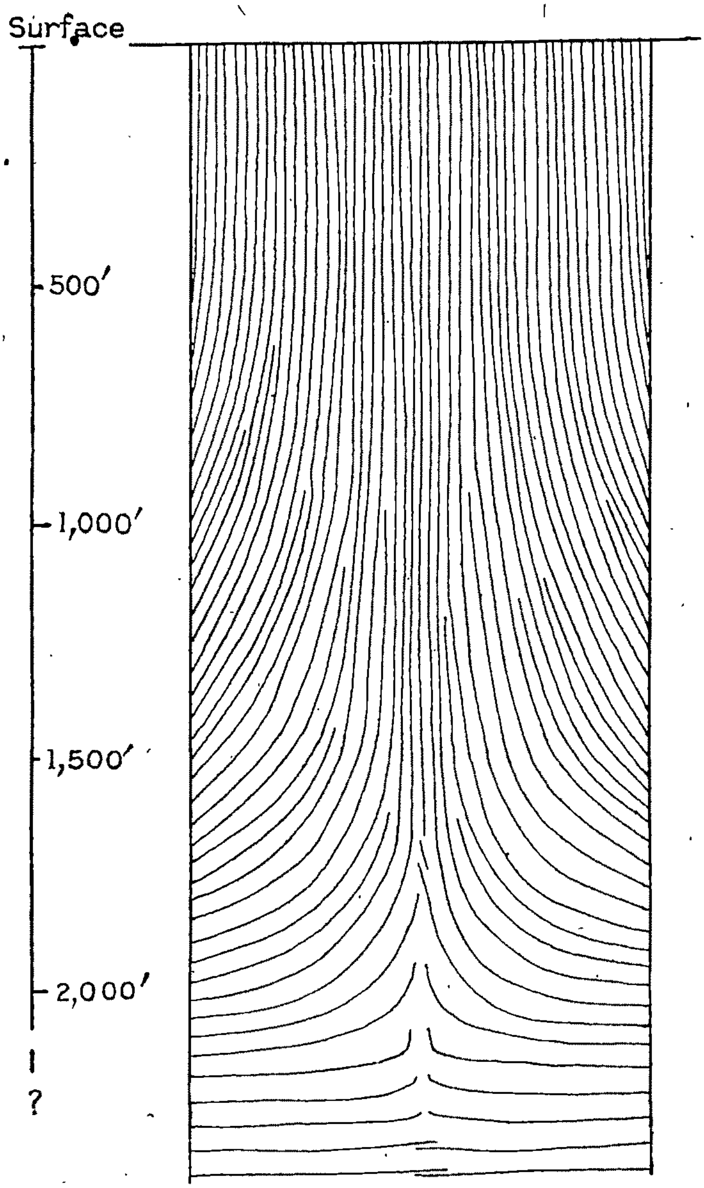

Fig. 1. Diagrammatic cross section through a volcanic neck to illustrate attitude of columnar joints in necks 1,000 feet in diameter in the Mount Taylor field, New Mexico. The portion of the section below the 2,000-foot level is not based on field observation and therefore is hypothetical.

joints in volcanic necks. Accepting the analysis of columnar joint development as discussed by Iddings,[2] it is easy to understand why the columns are vertical at the top of a neck and horizontal at considerable depth, but it is not immediately apparent (1) why they should converge upward instead of downward, (2) why they should curve outward with depth, and (3) why the individual columns should maintain their identity for such great lengths. The present paper, which attempts to answer these questions, is an outgrowth of a study of the numerous volcanic necks in the Mount Taylor region, New Mexico.[3] The helpful advice and criticism of my associates on the Geological Survey, particularly W. W. Rubey and P. G. Nutting, are gratefully acknowledged.

In the upper parts of the necks platy joints form a peripheral shell around the necks and are parallel with the outermost set of vertical columns. Slightly lower, the outer columns curve and meet the plates at low angles. At greater depth the inner columns curve sharply and meet the plates at high angles. There is no important structural relation between the plates and joint columns. Throughout this paper the platy jointing is ignored and the contact referred to in succeeding paragraphs is the inner side of the shell of platy joints.

There are two sets of columnar joints, forming more or less hexagonal columns. One set extends virtually continuously from the top downward and outward to the sides. These joints diverge slightly towards the contact so the columns there are larger than at the top. The larger parts of the columns are broken by similar joints that extend back up the column for perhaps a third of the distance to the top. This second and shorter set obviously developed from the contact inward and upward. The long set must have grown exclusively from either the side or top, otherwise the fractures would not be so continuous. We can safely assume they started in the most rapidly cooled portion of the pipe, that is, at the top. This paper is concerned only with the long set.

The strains induced by contraction during the cooling of igneous rocks that possess a finite tensile strength, basalt for example, cannot be expressed as cracks until the tensile stress

[2] Iddings, J. P.: Igneous rocks, pp. 320-327, 1920.

[3] Hunt, C. B.: Geology and fuel resources of the Southern San Juan Basin, New Mexico, Pt. 2, the Mount Taylor field: U. S. Geol. Survey Bull. 760-B, 1936. Hunt, C. B.: Structure and igneous geology of the Mount Taylor volcanic field, New Mexico: U. S. Geol. Survey Prof. Paper 189-A (in preparation).

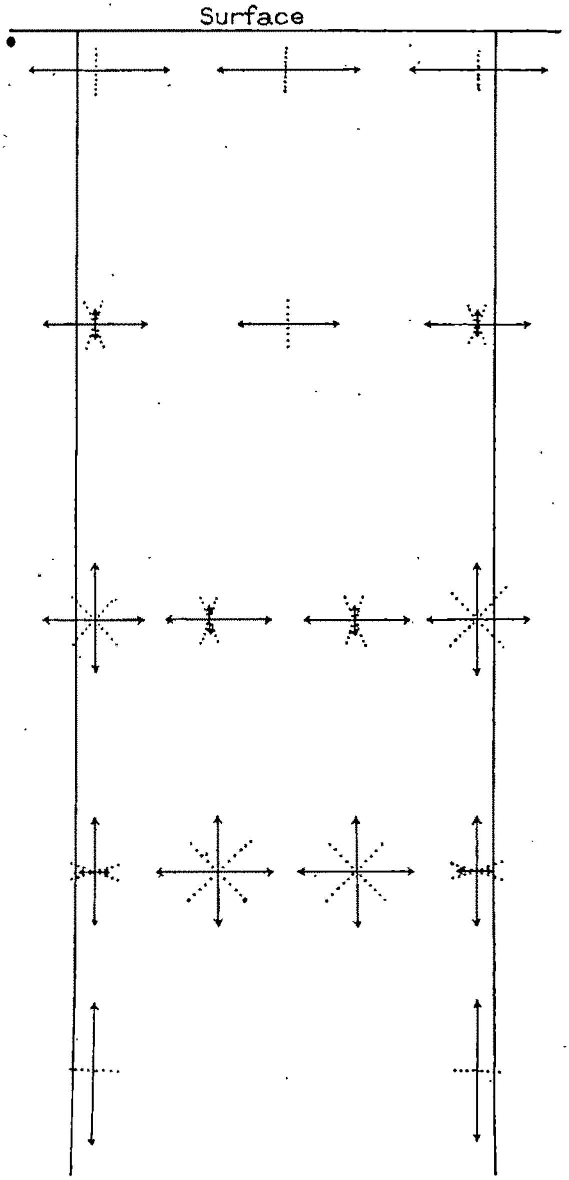

Fig. 2. Cross section of a volcanic pipe showing probable distribution of tensional stress ratios during cooling. Stresses indicated by arrows. At each point the relative amount of stress in each direction is indicated by lines of different length. The stresses can be relieved by fracture along the dotted lines, which are directions normal to the maximum resultants of the stresses. The diagram does not indicate relative amount of stress between two points.

overcomes the tensile strength of the rock. During the cooling of a cylinder of basalt the amount of heat that is lost is not the same at all points within the cylinder. At some given moment during cooling, therefore, contraction will have overcome the tensile strength of the rock in one part of the cylinder but not in others. In the following paragraphs an attempt is made to analyze the stresses due to temperature gradients throughout the pipe and to assess the probable effect of the first-formed cracks on the jointing that is to take place in the yet uncooled portions of the mass.

Assume for the upper 2,000 feet of a pipe (1) that the rate of heat loss vertically is equal at all points equally distant from the surface, and (2) that the rate of heat loss laterally is equal at all points equally distant from the walls. Actual conditions of cooling in a pipe are, of course, not so simple as assumed and such irregularities probably produce the observed departures from the ideal joint system sketched in Fig. 1.

The ideal distribution of stresses under the assumed thermal gradients for vertical cross sections passing through the axis of the pipe is shown in Fig. 2. Only two directions of stress are considered. The third direction normal to these two does not change the qualitative analysis and for the sake of simplicity it is not here considered. In the uppermost portion of the cylinder the cooling at the surface is very great compared to the cooling from the sides. This is demonstrated by exposures that reveal natural cross sections of ancient volcanoes. Such exposures show that the upper part of the pipes is made up entirely of vertical columns. Also, during the chilling of a pipe its upper portion chills sooner than the mass below it, and vertical cracks start in it before the next underlying portion has cooled sufficiently to produce stresses that exceed the tensile strength. Then, because gradation between these two adjacent portions is complete and because less tensile stress is needed to extend a crack already opened, it follows that the joint cracks started in the uppermost portion may be extended down into portions where the tensile stress may not be sufficient to start a new crack. The cracks that were first formed, in the uppermost portion, have a distinct advantage and prematurely relieve stresses in lower portions that are insufficient to start new cracks. This seems to explain why many individual cracks maintain their identity for such great lengths.

Now, at some depth below the surface,—observed at about 500 feet in necks 1,000 feet in diameter in the Mount Taylor field (Fig. 1)—the columnar joints show the first recognizable effect of lateral cooling. In a warm, solid, volcanic plug, each part of the plug below the surface is overlain by an only slightly

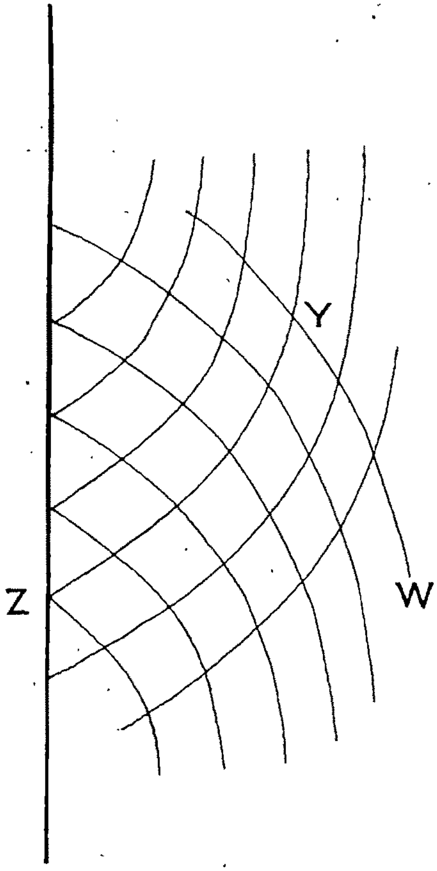

Fig. 3. Cross section adjacent to the contact of a volcanic pipe showing incipient fractures that are curved because the effect of lateral cooling diminishes inward from the contact and effect of vertical cooling diminishes with depth. The strains in this mass can be relieved by fracturing along either system. A crack extending down to the top of this mass will permit premature rupture and will select the direction YZ because that is the direction of increasing strain.

cooler part. The amount of heat that has been lost by vertical conduction, therefore, diminishes with depth, whereas the heat lost by lateral conduction remains constant for all points equally distant from the wall. Hence, with depth, the ratio of vertical over horizontal heat loss (or horizontal over vertical contraction) becomes smaller. But at any given level, cooling in the vertical direction remains constant all the way across the plug, whereas the effects of lateral cooling diminish toward the center. Therefore, the stress-ratio—horizontal over vertical tension—increases toward the center. It follows, then, that the stress-ratio near the contact at a given level is duplicated at some point inward from the contact at a slightly lower level. This progressive change of stress ratios and consequent progressive change in the direction of incipient cracks is illustrated in Fig. 2.

In Fig. 2, where the tensile stress in the horizontal plane exceeds the tensile stress in the vertical plane as, for example, near the contact in the second level of the figure, the strain can be relieved by fracturing along either of the dotted lines. Where the stresses in the two directions are equal the dotted lines will be inclined at 45° (contact at level 3). If only horizontal stress is present, the tensional fractures will be vertical (level 1).

Consider first the depth on the side of the cylinder where the stresses due to vertical cooling have so diminished that the resultant between them and the stresses due to lateral cooling tend to develop fractures deviating only slightly from the vertical. These resultant stresses can affect the extension of a crack already started from above, even though they are not sufficient to create a new crack. This condition is shown diagrammatically at second level of Fig. 2. The incipient cracks at such a point near the contact are represented more fully by Fig. 3, a cross section adjacent to the contact of a volcanic pipe. The stresses in the pipe can be relieved by fractures opening along either of the two incipient fracture systems. An existing crack that has extended itself down to the top of this mass has advantage over the incipient cracks of either system. It will be extended downward and develop the incipient cracks of whichever of the two systems possesses a mechanical advantage over the other.

Assume that the crack has formed from the surface and extended down to Y. It may now curve to point Z or point W. But the contraction is greatest towards Z—the direction of greater heat loss. Y to W is toward the center of the pipe and is therefore a direction of diminishing contraction, whereas Y to Z is a direction of increasing contraction. Evidently the crack will curve outward to Z.

With increasing depth the incipient cracks near the contact progressively approach a horizontal position (see Fig. 2). But at any given level the incipient fracture system that curves downward and outward to the contact will be preferred just as the incipient cracks of similar, though more nearly vertical, position were preferred at the higher levels. In the interior, where the stress-ratios near the contacts of the higher levels are duplicated, the cracks extending from above will also be curved outward towards the side, though less so than near the side. At some great depth, more than 2,000 feet for pipes 1,000 feet in diameter in the Mount Taylor field, the rate of lateral cooling, even though slight, must be very great compared to the rate of cooling vertically. Probably at such depths the columnar joints are nearly horizontal and developed inward from the contacts.

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TWO ANALYSES OF TRAP ROCK FROM THE HOLYOKE RANGE IN MASSACHUSETTS.

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ABSTRACT.

Analyses of two samples of Mt. Holyoke diabase have been made, using semi-micro methods; the norm of the rock calculated; and the thin-section described.

The chief purpose of this note is to place on record the results of semi-microchemical analyses of two selected samples of diabase from the Holyoke Range in Massachusetts. The samples for the analyses were selected because of the possible geological relations of two major igneous rock masses of the range: one, the main trap sheet of Holyoke diabase as it is called by Emerson,[1] and the other, a large dike which, it is thought, cuts the main sheet.

One sample was taken from the main sheet in the large quarry at the "Notch" located on the Amherst-South Hadley road. It was removed from the east wall not far above the present level of the quarry floor and about 75 feet below the eroded summit surface. It was not possible to determine the exact position of the specimen within the sheet, which in the range, has been estimated by Emerson[2] to be about 400 feet thick. However, it is likely that the sample was taken from a position not far from the middle of the sheet. The other sample was taken from a dike about three miles west of the "Notch" at the locality known as "The Black Rock."[3] The dike cuts through the sandstones overlying the main sheet and apparently fills a feeding fissure of the Hampden diabase sheet, which overlies the sandstones. The main trap sheet, dipping southerly, passes beneath the surface at this locality, but the field relations indicate that the dike cuts it at some depth. The specimen was removed from the freshly quarried trap at a point about 339 feet from its northern contact with the sandstones that it cuts, and at a distance below the surface of the ridge estimated to be 100 feet. Conditions at each locality made possible the selection of freshly exposed unweathered material.

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[1] Emerson, B. K.: Geology of Massachusetts and Rhode Island. U. S. Geol. Survey Bull. No. 597, 1917.

[2] Loc. cit.

[3] Emerson, B. K.: Geology of Old Hampshire County, Massachusetts. Mon. U. S. Geol. Surv. XXIX, 489, 1898.

Semi-micro methods of chemical analysis were used, following in general the procedure of Guthrie and Miller[4] with adaptations, in certain determinations, of megascopic methods taken from several sources; these included: preparation of the sample, W. F. Hillebrand[5]; determination of alkalies, titanium, ferrous iron, phosphorus, and manganese, H. S. Washington[6]; and determination of the alkaline earths, Willard and Furman.[7] In the preparation of the rock powder, every effort was made to insure a homogeneous sample, the rock being crushed to a particle size sufficiently small to permit the passage of all grains

TABLE I.

	Main Sheet				*Dike*		
	% Found	% Diff.	%Av.		% Found	% Diff.	%Av.
SiO_2	50.42			SiO_2	50.34		
	50.40	.02	50.41		50.17	.17	50.25
TiO_2	1.04			TiO_2	1.32		
	.99	.05	1.01		1.26	.06	1.29
Al_2O_3	....			Al_2O_3	....		
	....	..	16.40		....	..	15.20
Fe_2O_3	....			Fe_2O_3	....		
	....	..	.14		....	..	.38
FeO	10.45			FeO	12.61		
	10.21	.24	10.33		12.57	.04	12.59
MnO	.16			MnO	.19		
	.14	.02	.15		.18	.01	.18
MgO	6.83			MgO	6.43		
	6.97	.14	6.90		6.42	.01	6.42
CaO	10.16			CaO	10.29		
	10.10	.06	10.13		10.29	.00	10.29
Na_2O	2.68			Na_2O	1.80		
	2.56	.12	2.62		1.69	.11	1.74
K_2O	.85			K_2O	.57		
	.78	.07	.82		.57	.00	.57
P_2O_5	....			P_2O_5	....		
	....	..	trace		....	..	none
H_2O+	....			H_2O+	....		
	....	..	.92		....	..	1.03
H_2O-	....			H_2O-	....		
	....	..	.46		....	..	.26
Total			100.29	Total			100.20

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[4] Mineralog. Mag. XXIII, 405-415.

[5] The Analysis of Silicate and Carbonate Rocks. U. S. Geol. Survey Bull. No. 700, 1919.

[6] The Chemical Analysis of Rocks. 4th Edition, John Wiley and Sons. New York, 1930.

[7] Elementary Quantitative Analysis. 326-332. D. Van Nostrand Co., New York, 1933.

through a 100-mesh bronze sieve. For the determination of the oxides of silicon, titanium, the alkaline earths, and total iron a 100 milligram sample was used. The oxides of manganese, ferrous iron, the alkalies, combined water, and hydroscopic water were determined in separate 100 milligram samples. For the phosphorus determination, a 200 milligram sample was employed. Aluminum and ferric oxides were found by difference. Platinum ware was used for all fusions, ignitions, and evaporations. The time required to run an analysis in triplicate for thirteen constituents was about 35 hours.

TABLE II.

	Main Sheet	*Dike*
Quartz	....	1.02
Orthoclase	5.00	3.34
Albite	22.00	14.67
Anorthite	30.58	31.97
Diopside	16.08	15.77
Hypersthene	13.30	29.00
Olivine	9.55	....
Magnetite	.23	.46
Ilmenite	1.98	2.28
	98.72	98.51
Total Salic Minerals	57.58	51.00
Total Femic Minerals	41.14	47.51

The data in Table I suggest two conclusions: first, a marked similarity of chemical composition of the two samples; and second, an acceptable duplication of results by using semi-micro methods.

From the data in Table I, the norm of each rock was calculated, with the results shown in Table II.

According to the quantitative system of classification devised by Cross, Iddings, Pirsson and Washington,[8] on the basis of the data in Table II, each specimen can be classified as Auvergnose.

Thin sections were examined under the polarizing microscope. The most abundant minerals of the dike are idiomorphic lath-shaped crystals of feldspar (labradorite and probably andesine), surrounded by shapeless grains of augite and a mineral identified as enstatite. Magnetite, mostly as small grains but with a few well-developed octahedra, is scattered in moderate abundance throughout the section, generally imbedded

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[8] Quantitative Classification of Igneous Rocks. The University of Chicago Press. Chicago, 1903.

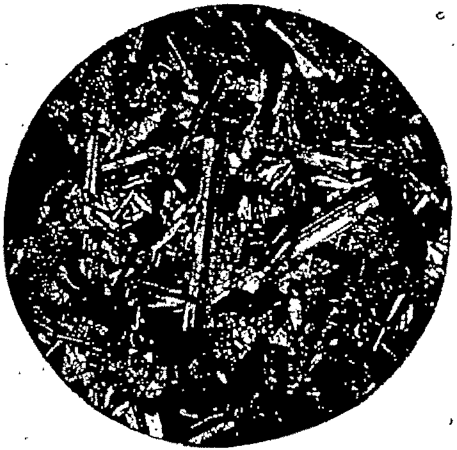

Fig. 1. Photomicrograph, using polarized light, of section taken from the Dike showing lath-shaped crystals of feldspar.

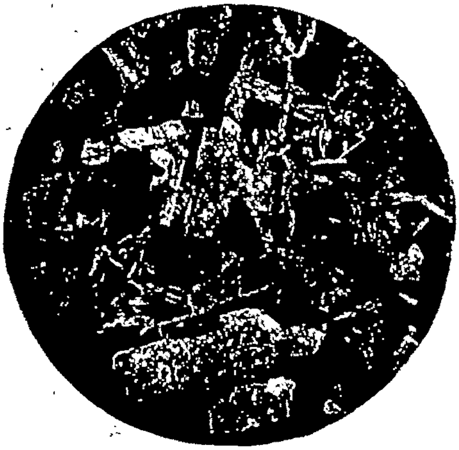

Fig. 2. Photomicrograph, using polarized light, of section taken from Main Sheet showing the diabasic texture and phenocrysts of feldspar.

in the pyroxene. There is considerable interstitial brown or green glass. The sequence of crystallization appears to be feldspar, magnetite, pyroxene, and residual glass. In the thin section from the main sheet, the diabasic texture was seen to be well developed. The chief components closely resemble those found in the dike, except that the section shows the complete absence of glass. Megascopically, each specimen is a dark gray aphanitic rock with scattered phenocrysts of feldspar measuring nearly one millimeter in length and often displaying polysynthetic twinning.

A study of the data in Tables I and II, supplemented by the thin-section study, suggests that the main sheet and the large dike, which presumably cuts it, are genetically related; the difference is one of degree, the main sheet being more salic than the dike. The results support the use of semi-micro methods in rock analysis and the procedure affords a considerable saving of time.

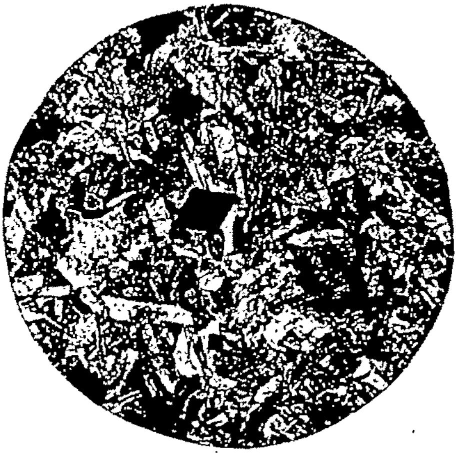

Fig. 3. Photomicrograph of section taken from Main Sheet showing a well developed octahedron of magnetite.

The writer wishes to acknowledge the kindness of Dr. A. C. Lane, of Tufts College, for suggesting that these analyses be made; he wishes also to thank Dr. C. E. Gordon, of the Geology department, for assistance in the field work and suggestions concerning other geological aspects of the problem, and Dr. C. A. Peters, of the Chemistry department, for helpful suggestions in the analytical treatment of the problem.

MASSACHUSETTS STATE COLLEGE,
AMHERST, MASS.

SCIENTIFIC INTELLIGENCE.

PHYSICS.

A College Course in Sound Waves and Acoustics; by M. Y. COLBY. Pp. xi, 356; 109 figs. New York, 1938 (Henry Holt and Co., $2.80).—This text-book is designed to follow a normal one-year college course in elementary physics. In comparison with other texts on this subject it places emphasis upon giving the student a grasp of the many recent industrial, commercial and domestic applications of sound and acoustics, without too rigorous mathematical analysis. There is a preliminary survey of the physical principles of sound in the first chapter which provides a brief review as introduction to the subject. This is, however, extremely elementary and may easily be omitted. The next three chapters present an extended discussion of vibratory motion in general and of transverse and longitudinal waves, in standard fashion with a minimum of mathematics. Modern developments are introduced beginning with the chapter on longitudinal vibrations of bars, in an account of the behavior and uses of piezoelectric oscillators and supersonics. Ensuing chapters deal with vibrating air columns, interference and allied effects, the theory and practice of intensity measurement, hearing, and architectural acoustics. Especial pains are taken with the treatment of superposition of wave trains and its applications, particularly with regard to beat and combination tones. Numerous problems are to be found at the end of each chapter, and in an appendix are sets of objective questions of the completion form, to be used following each chapter. While extensive use is of course made of trigonometry, no calculus is required beyond a knowledge of first derivatives. For this reason mathematical circumlocution is often necessary and this detracts from the book's usefulness as a reference text. A. T. WATERMAN.

Experimental Radio; by R. R. RAMSAY. Pp. xiv + 196; 167 figs. Fourth edition. Bloomingdale, Indiana, 1937 (Ramsay Publishing Co., $2.75).—Teachers, students, and especially amateur experimenters in the radio field will welcome this fourth edition, which brings up-to-date the edition of ten years ago. While the book is similar to the previous edition in aim, scope and method of presentation, the size of the volume has been enlarged to that of an ordinary text instead of appearing again in handbook size. As before, the book follows the style of a laboratory manual in progressing from simple basic facts to more complicated measurements and circuits, and retains the great advantage to an amateur of minimizing the use of costly and elaborate apparatus. In bringing the subject matter up-to-date the chief modification lies in the substitution, where convenient, of rectified alternating current sources for batteries, following the development of commercial radio sets in this respect. A. T. WATERMAN.

GEOLOGY.

The Structural History of Australia during the Palaeozoic. (The Stabilization of a Continent.); by E. C. ANDREWS. Jour. Proc. Roy. Soc. New South Wales, vol. 71, pp. 118-187, 1 pl., 7 text figs., 1938.—This interesting and far-reaching paper reviews the geologic formations of Australia, for the purpose of ascertaining the essential structural elements of this vast continent, and the main times of orogenic movement during the Paleozoic era. Plate I shows graphically the three ancient nuclei and the thirteen other structural elements or masses. The orogenic events are grouped into three categories: (1) at the close of the Proterozoic, (2) the Caledonian orogenies (inclusive of the Devonian), and (3) the Hercynian-Appalachian movements of the crust. Another excellent result of Andrews's studies is the seven paleogeographic maps, one each for Upper Pre-Cambrian, Cambrian, Ordovician, Silurian, Devonian, Lower Carboniferous, and Middle Permian times. He finds no demonstrable Upper Carboniferous.

In conclusion, Andrews says:

"Australia thus appears to have arrived at its present advanced state of stability by the welding, or knitting together of: (1) The ancient nuclei: Stuartiana, Yilgarnia, and Willyama, during the Caledonian orogeny." Later "knitting action" took place during the Hercynian (inclusive of Appalachian) orogeny. (3) "The sediments affected by Caledonian and Hercynian activities were deposited in long-enduring geosynclines with complex histories." The movements "progressed, generally, as from west to east," and more specifically "from south-west to north-east in eastern Australia." "The greater portion of the old (eastern) borderland, 'Tasmantis', has now sunk beneath the sea" (pp. 186-187).

CHARLES SCHUCHERT.

Palaeozoic Formations in the Light of the Pulsation Theory. Vol. III, Cambrovician Pulsation. Pt. II. Appalachian, Palaeocordilleran, Pre-Andean, Himalayan and Cathaysian Geosyncline; by A. W. GRABAU. Pp. 850, 58 text figs., maps and correlation charts in pocket, Nat. Univ. Peking, 1937 ($5.50; sales agent: The French Bookstore, Peiping).—The Pulsation Theory, set forth by Grabau in the present series of volumes, seeks "to explain the observed phenomena of transgression and regression in terms of periodic rise and fall of the sea-level." Volume I treated of the Taconian (Lower Cambrian) and the Cambrian (Middle Cambrian) pulsation systems or periods. Vol. II is concerned with the Cambrovician pulsation; its Part I, dealing with the Caledonian and St. Lawrence geosynclines, was discussed by the reviewer, together with Vol. I, in the issue of this Journal for December, 1937, pp. 475-479.

The Cambrovician pulsation includes Upper Cambrian, Ozarkian, Tremadocian, Canadian, and Arenigian; "whether these will continue to be regarded as a unit Pulsation System, or eventually will have to be divided into two; Ozarkian and Canadian, will depend on the result of further investigation" (p. iii). "From the pulsationist's point of view, the independence of the Ozarkian Pulsation System on the one hand, and of the Canadian Pulsation System on the other, can only be established by the recognition, in the geosynclinal regions, of the evidence of retreat of the sea, after the Upper Cambrian advance, and furthermore, the discovery of indubitable evidence of re-advance of the Early Canadian Sea after an interval of exposure" (p. iv). In Appendix III, the author indicates that he is inclined to the view that eventually the third Pulsation System will be known as the Ozarkian, and the fourth as the Canadian.

The Cambrovician of eastern North America is described on pages 1-210, and is followed by that of Cordilleran North America (211-328), the Pre-Andean geosyncline (329-351), South Africa (352-365), Australasia-Antarctica (366-391), the Himalayan geosyncline (392-411), China (412-606), and boreal Asia (607-638); succeeding these are tables of faunas (639-721), eight Appendices (722-800), and Indices.

Plate III gives, in colors, the paleogeography throughout Pangea; IIIb that of North America; and IIIc that of Asia. There are also six correlation charts.

We are pleased to read, on pages 742-755, Grabau's views regarding the depth of the waters (12,000 feet) in which the radiolarite of the Lower and Middle Ordovician of the Hudson Valley was said to have been formed, and especially his conclusion that "We may still perhaps be permitted to subscribe to our original concept of the geosyncline, and to continue questioning the possibility of abyssal areas in geosynclines." We agree with Grabau that here "paleontological enthusiasm has run ahead of stratigraphic caution."

Whatever may be our views about the Pulsation Theory and the author's paleogeography of a Pangea, it is clear that this gazetteer of the world's stratigraphy must be in the working library of every geologist who is concerned with areas greater than local ones. CHARLES SCHUCHERT.

ZOOLOGY.

Aus. Dem Leben der Vögel (From the Life of Birds); by OSKAR HEINROTH. Pp. x, 165; 98 figs. Berlin, 1938 (Julius Springer, RM. 4.80).—This is another little book—the 34th—of the *Verständliche Wissenschaft* series. After a brief introduction to the chief characteristics of birds the author answers very clearly many questions which are not treated in most ornithological books. Does the bird recognize its own eggs and young? Who feeds and trains the young? Is the size of the egg always related to the size of the bird? How does the bird find its way?

Among other aspects of bird life the following are briefly presented: parasitic birds, hybridization, courtship and mating, composition of eggs, growth and development of the young, coloration, care of the feathers, calls, songs and their meaning, types of movement, and intelligence.

Especially to be commended are the photographic illustrations; they are appropriate, original, clear, and well reproduced.

One feels that so excellent a little book should have had its usefulness extended through a brief bibliography. S. C. BALL.

BIOLOGY.

Handbuch der Biologischen Arbeitsmethoden, edited by EMIL ABDERHALDEN. Berlin (Urban & Schwarzenberg). Abt. IX, Methods for the Study of the Behavior of Animals, Teil 6, Heft 4, on methods of marine biology, Lieferung 471, 1938 (price, RM. 9.50, minus 25% discount), contains two articles. The first is by CARL I. CORI on *Narcosis and Anaesthesia of Invertebrates in Fresh- and Salt Water,* pp. 543-584. The second is by CARL I. CORI, THILO KRUMBACH, and HJALMAR BROCH on *A General Viewpoint for the Arrangement of Biological, Hydrographical Marine Institutes and Fishery Stations,* pp. 585-677, 11 figs. and 1 map showing the location of the world's marine stations.

The present number continues the usefulness of this well-known serial. It contains a table of contents and index for Abt. IX, Teil 6. S. C. BALL.

The Human Value of Biology; by JOHAN HJORT. Pp. xii, 241; 29 figs. Cambridge, Massachusetts, 1938 (Harvard University Press; price, $2.50).—In reading this book one may well wish that he might have listened to Dr. Hjort at the University of Oslo in 1936 as he delivered to his students the lectures which, revised, have been published in this thoughtful and thought-provoking volume. For it whets one's appetite for more of the philosophy of Kant and Goethe, Adam Smith and Malthus, and of others whose ideas are so ably introduced in relating these philosophies to the history and to the present status of biological science. Biology had its own Renaissance after the Napoleonic wars, and this has long stimulated the author to put to use his researches into problems of marine populations—fishes, whales and prawns—in the understanding and improvement of human populations. So the last part of the book is devoted to biology and the science of population, biology and social service, and sociology in the light of biology.

To our comfort of mind he shows that a new industry can develop without any danger to existing society; it may provide new work without throwing laborers out of positions in older industries. This truth is illustrated by the Norwegian prawn-fisheries which were founded and fostered by Dr. Hjort's own researches. He would carry over into industry even more extensively than hitherto the biological principle of division of labor, trusting to man's inventiveness in opening a multitude of new divisions. Using as a basis the controlled population studies of Pearl and other workers, the author shows that the human maximum individual standard of life is coincident with an optimum population, not with a maximum population. S. C. BALL.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Proceedings of the Florida Academy of Sciences, Vol. I, 1936; pp. 170; frontispiece and 10 figs. Gainesville, 1937 (University of Florida; $1.00).—Reports the founding and first year's activities of this new Academy of Science. It contains several important papers covering a wide range of subjects. One which deserves study by educators is C. P. Heinlein's stimulating article on *Some Consequences of Pseudo-mathematics and Quasi-measurement in Psychometrics, Education and the Social Sciences.* Page headings inadvertently conclude with the last L. L. Rusoff's paper on vitamin chemistry. The Achievement Medal for 1936 was awarded to H. H. Hume for his studies on *Cohering Keels in Amaryllids.*

To zoologists the following papers are of interest: *Key to the Fresh-water Fishes of Florida,* by A. F. CARR, JR.; *Annotated List of the Birds of Alachua County,* by R. C. MCCLANAHAN; *List of the recent Wild Mammals of Florida,* by H. B. SHERMAN; Plant chemistry is represented by a paper on *The Cellulose of Spanish Moss,* by L. E. WISE and A. MEER. Several other articles as well as abstracts of 23 additional papers read at the spring and fall meetings add to the value of the volume. S. C. BALL.

OBITUARY NOTES.

DR. A. E. ALDOUS, professor in the department of agronomy of the Kansas State College of Agriculture and Applied Science, died on May 5 at the age of fifty-one.

DR. FRED BAKER, the conchologist, died in San Diego on May 16 in his eighty-fourth year. His collection of shells, said to be the largest privately owned collection in the west, will go to the San Diego Society of Natural History, of which he was vice-president.

DR. ROBERT MONTGOMERY BIRD, professor of organic chemistry at the University of Virginia, died on June 4 at the age of seventy-one.

PROF. WILLIAM ARTHUR BONE, one of the leading British experts in the use of coal and fuels, died in London on June 11 at the age of sixty-seven. He was chief professor and head of the department of chemical technology at the Imperial College of Science and Technology, London University, 1912-36.

MR. B. D. BURITT, survey botanist in the Department of Tsetse Research, Tanganyika Territory, Africa, died on June 8.

DR. WILLIAM WALLACE CAMPBELL, for. Mem. R.S., president of the University of California in 1923-30, director of the Lick Observatory in 1901-30, died on June 14, aged seventy-six.

PROF. GEORGE W. CAVANAUGH, who became professor emeritus of chemistry at Cornell University on his retirement two days before his death, which took place on July 1 at the age of sixty-eight.

DR. GÉZA DE HORVÁTH, noted entomologist, died on September 8, 1937, in his ninetieth year. He worked at the head of the department of zoology at the National Museum, Budapest. Here as a specialist on the Hemiptera, he acquired a world-wide reputation.

PROF. JAMES LAWRENCE KELLOGG, professor emeritus of the department of biology at Williams College and an authority on shellfish, died on July 8 at the age of seventy-one. Professor Kellogg did much research work for the Federal Government Department of Fisheries at Woods Hole.

The REV. CASTOR ORDONEZ, head of the department of biology at De Paul University since 1916, died on June 28 at the age of fifty-eight.

MR. HUGH RAMAGE, noted biochemist, working at Dublin, Royal College of Science and at Cambridge, died on April 16 at seventy-three years of age. He was the principal of the Technical Institute at Norwich from 1904 to 1930.

DR. SINCLAIR SMITH, physicist at the Mount Wilson Observatory, died on May 18, aged thirty-nine.

PROF. WILLIAM STROUD, chairman of the firm of Barr and Stroud, died at the age of seventy-nine years on May 27, at Torquay, England. In 1885, he was made Cavendish professor of physics at the Yorkshire College of Leeds where he remained until 1909. He then devoted himself to his business in Glasgow, where he invented, in collaboration with his partner, Mr. Barr, the range-finder and many other valuable appliances.

MR. CHARLES FRANCIS MASSY SWYNNERTON, director of Tsetse research in Tanganyika Territory, Africa, died on June 8, aged sixty.

MR. FRANK BURSLEY TAYLOR, of Fort Wayne, Ind., who was connected with the U. S. Geological Survey from 1900 until his retirement in 1916, died on June 12 at the age of seventy-eight.

AMERICAN JOURNAL OF SCIENCE

SEPTEMBER 1938

GEOLOGY OF THE CARIBOU STOCK, IN THE FRONT RANGE, COLORADO.

WARD SMITH.

ABSTRACT.

The Caribou stock is a composite Tertiary (?) intrusive mass in southeastern Boulder County, Colorado, near the center of the pre-Cambrian crystalline core of the Front Range. The stock is composed chiefly of monzonite, but masses of titaniferous magnetite and bodies of ultramafic and gabbroic rocks make it unique among the intrusives of the range. Its unusual features have been explained by earlier workers in different ways: Jennings in 1913 concluded that the ultramafic rock and the magnetite had formed as dikes intruded into the monzonite. Bastin and Hill (1917) gave the first full description of the stock. They found a striking variety of rocks: quartz monzonite, monzonite, olivine monzonite, gabbro, hornblende gabbro, hornblendite, magnetite-rich gabbro, magnetite peridotite, magnetite pyroxenite, titaniferous magnetite. They explained these rocks as products of magmatic differentiation, formed by "separation of the molten magma into portions that were chemically different." In 1935 Reynolds suggested that the Caribou monzonite might be a product of hybridism, generated from surrounding pre-Cambrian schists by the action of a biotite pyroxenite magma. Lovering and Goddard in 1938 interpreted the gabbro as an earlier border facies of the monzonite, and the ultramafic rocks and titaniferous magnetite as products formed when xenoliths of the (pre-Cambrian) lime-silicate rocks reacted with the gabbro and monzonite magmas.

The present study leads to the conclusion that the composite mass was formed from separate, successive intrusions, in the following order: (1), magnetite-rich pyroxenite; (2), augite gabbro; (3), augite monzonite; and (4), minor varieties—aplite, pegmatite, monzonite porphyry, and lamprophyre. It is suggested that crystallization of the silicate minerals from the oldest, ultramafic magma produced an iron-rich residue which was concentrated by filter-pressing to form masses of titaniferous magnetite. A noteworthy feature of the stock is hornblendization, which affected each primary augitic rock type in a different degree. Some masses of pyroxenite have been completely hornblendized; in gabbro the hornblende is in patches and diffuse veinlets; in monzonite, there are thin, sharply defined hornblende seams which are prominent in many places as veneers on joint blocks.

GEOGRAPHIC AND GEOLOGIC SETTING OF THE STOCK.

Location and Topography.

The Caribou stock is in the southwestern corner of Boulder County, Colorado, near the middle of the Front Range, at latitude 40° N. and longitude 105° 35′ W. It lies partly on the north margin of the Central City quadrangle and partly on the adjacent Rocky Mountain National Park quadrangle. Its location as well as its geologic setting are shown on Pl. 1, which is taken from Lovering's report on the nearby Montezuma quadrangle (1935, Pl. 5). The section included in the outline marked on this map comprises about 70 square miles surrounding Caribou; it is the area covered during the study of the stock.

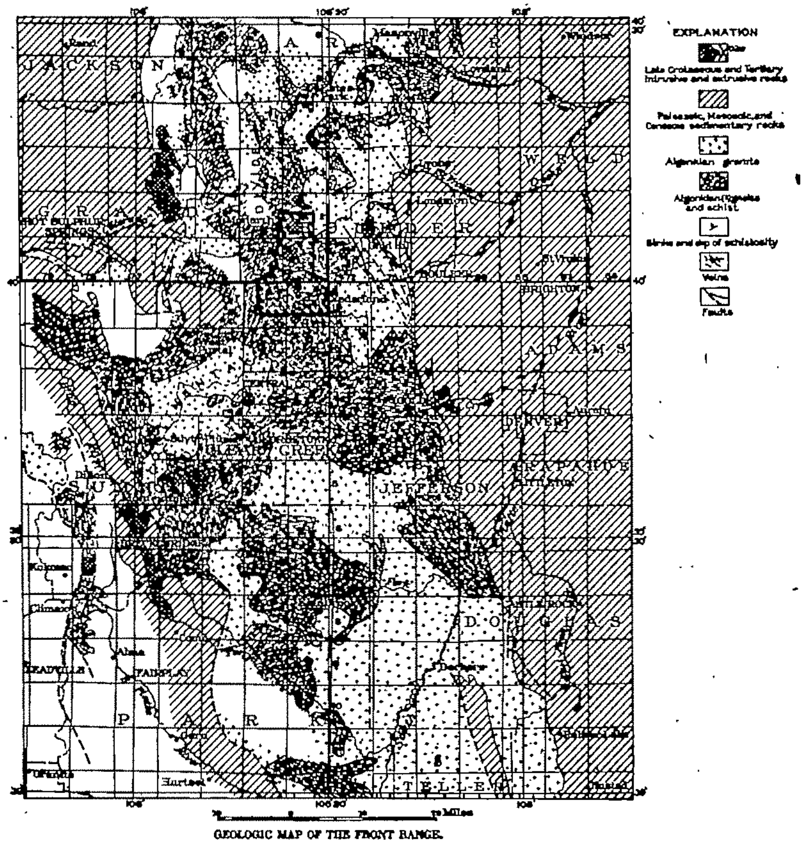

Plate I. Geologic map of the Front Range (from T. S. Lovering, U. S. Geol. Surv. Prof. Paper 178, pl. 5, 1935). Heavy hachured line marks area surveyed during study of the Caribou stock.

It will be seen from Pl. 1 that about 90 per cent of the crystalline core of the Front Range is pre-Cambrian schist, gneiss, and granite; the other ten per cent comprises Tertiary stocks and dikes. In the complex of crystalline rocks the outlines of schist and granite areas are very irregular and the schist structure shows a great diversity of attitudes. The stocks and dikes intrusive into the pre-Cambrian complex are generally considered to be Cretaceous or Tertiary in age (Lovering, 1935, p. 26); for the sake of brevity they will be referred to as Tertiary in this report. Most of the stocks lie in a belt which extends N. 40 E. across the range from Breckenridge, near the west border, to Longmont, at the east margin. A second, shorter row of stocks diverges from the first near the center of the range and extends northward. The stocks of this north-south line, together with the surrounding pre-Cambrian schist and gneiss, were examined, though not in detail, and a generalized map was prepared (Pl. 2). For the central, most complex part of the Caribou stock a detailed plane table map was prepared. (See Pl. 3.)

To have shown the topography by contours would have added confusing lines to the geologic maps, and therefore none are drawn. Topographically the area included in Pl. 2 may be pictured as a part of the east slope of the Front Range, with the range crest forming the western boundary of the area. From Arapaho Peak, which stands 13,506 feet above sea level, the area extends eastward across progressively lower and more subdued topography to the minimum altitude of 8,500 feet. Near the crest of the range matterhorn peaks, serrate ridges, and steep-walled cirques are typical, but on unglaciated ridgetops remnants of a subdued topography are preserved. Many ridges are asymmetric, with a steep cirque wall on the north or northeast and a smoothly curving slope on the opposite side. Wide-topped spurs extend eastward from the Continental Divide and between them lie the broad-bottomed valleys of the main east-flowing streams. On the smooth curves of the higher ridges there are many partly-formed cirques, but the principal effect of glaciation is a deepening and widening of valleys already much entrenched in a surface of moderate relief. Some of the main valley bottoms are 1,500 feet below the adjacent ridges. Still farther east the topography is relatively subdued, although some of the country is fairly rugged, with a relief ranging up to a maximum of about 700 feet. Within this eastern portion the principal action of glaciers was the deposition of moraines and outwash gravels. Inasmuch as glacial drift covers much of the ground in this eastern portion, the exposures are less satisfactory than farther west.

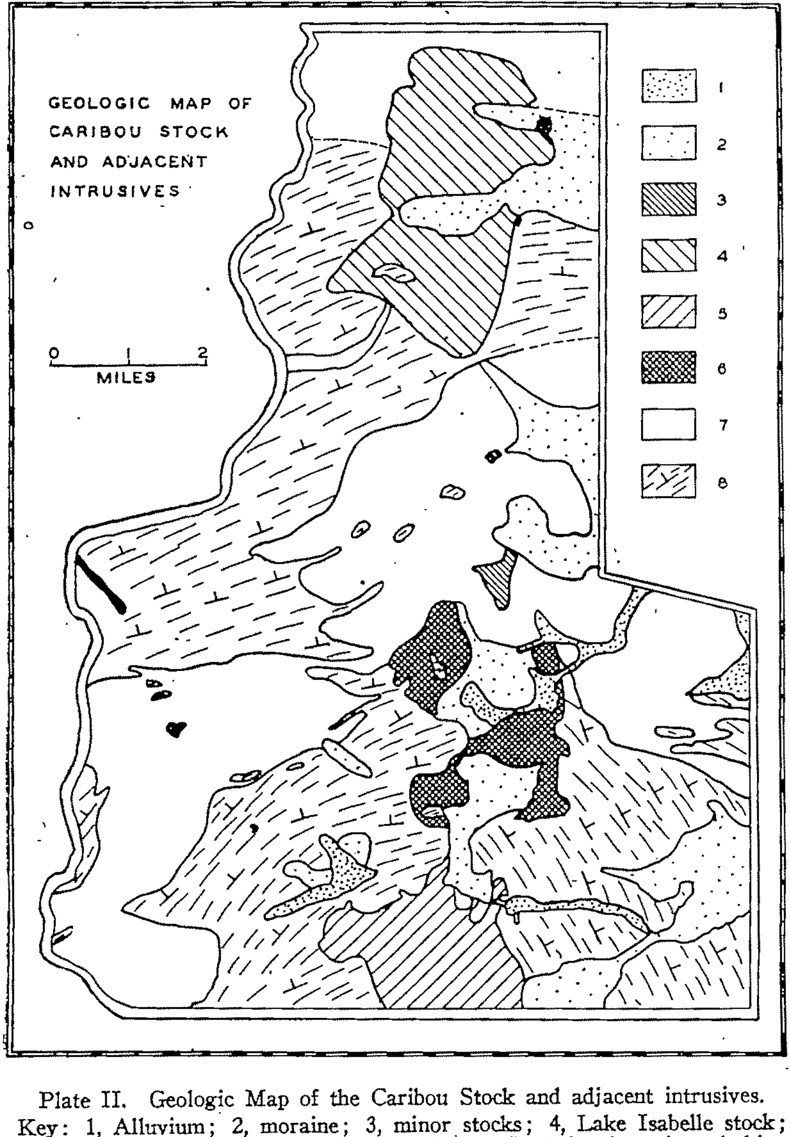

Plate II. Geologic Map of the Caribou Stock and adjacent intrusives. Key: 1, Alluvium; 2, moraine; 3, minor stocks; 4, Lake Isabelle stock; 5, Eldora stock; 6, Caribou stock; 7, pre-Cambrian intrusives (white, granodiorite gneiss; black, Silver Plume (?) granite); 8, Idaho Springs schist and gneiss.

Pre-Cambrian Rocks.

Of the pre-Cambrian rocks, the schists and gneisses of the Idaho Springs formation are the oldest. This formation was originally a thick series of sediments, mostly fine-grained detrital material with a few calcareous layers; it now consists of about equal parts dark schist and light granitic injection material. The principal lithologic type in the formation is quartz-biotite schist, much of which contains sillimanite and some of which is garnetiferous. Rare types are quartzite, quartz-epidote rock, and actinolite-diopside-calcite rock. Intimately associated with the foregoing metamorphosed sedimentary rocks, and mapped with them as part of the Idaho Springs formation, are hornblende schist and gneiss layers, mostly metamorphosed igneous rocks. (The Swandyke gneiss which Lovering (1935, pp. 10-11) found in the Montezuma quadrangle is a thick series of metamorphosed andesite and basalt flows conformably overlying the Idaho Springs formation. No equivalent series was found in the Caribou area.) A great quantity of granite gneiss, pegmatite, and aplite appears as injection material in the Idaho Springs gneiss; it can be seen in almost every exposure, and it probably makes up about half the volume of the formation. In the field it is obvious that there are several ages of such granitic injection. At a single exposure one may distinguish as many as two generations of felsic material parallel to the schistosity and two that cut the layering.

The regularity in attitude and the even banding on most large exposures of the Idaho Springs formation suggests a uniform layering, but inspection invariably shows that the members are lenticular with no unit traceable for more than a few hundred feet. Because of this lack of distinctive units, no stratigraphic sequence or thickness has been established for the formation, and the structure shown on the map is generalized. However, as can be seen from the map (Pl. 2) the attitudes of the schistosity in the southern part of the area suggest that the Idaho Springs formation there forms a north-pitching anticline limited on the north by granodiorite gneiss and interrupted along its axis by the Caribou and Eldora stocks.

The granodiorite gneiss is concordant with the schistosity of the Idaho Springs formation, and it is apparent that the structure of the older rocks strongly controlled the form of the intrusion. The interfingering of thin, wedge-shaped layers of gneiss and schist is particularly well shown in the vertical sections of the contact that are exposed in cirque walls near the crest of the range, but at all contacts one is impressed with the evidence for lit-par-lit intrusion into the Idaho Springs formation. The rock is strongly gneissic, but it is uncertain how much of the foliation is a primary structure produced by flowage. Thin-sections show crystalloblastic features, such as biotite clusters and mosaic aggregates of quartz, which indicate that the foliation of the rock is partly a product of secondary, post-deformational crystallization. The granodiorite gneiss of this study included a mass between the Caribou stock and the eastern boundary of the area (Pl. 2) which was mapped by Bastin as Silver Plume granite (cf. Bastin, 1917, Pl. 1). Lithologically the rock is a coarsely porphyroid hornblendic biotite granodiorite, quite unlike the Silver Plume biotite granite of the type area. It is probable that further mapping will show that the gneiss is a marginal part of the Boulder Creek batholith, which covers a wide area east of Caribou.

Granite that may be equivalent to the Silver Plume forms one small stock and several dikes in the west-central part of the area (Pl. 2). The stock, about a quarter of a mile in diameter, invades the granodiorite gneiss discordantly; the dikes, which range up to 300 feet in thickness, cut the Idaho Springs formation. The rock is a light-gray to pink, medium-grained biotite granite, lithologically like the Silver Plume granite of Bastin (1917, pp. 35-37). Inasmuch as there are only small, isolated masses of this material, which cannot be traced directly to the type locality of the Silver Plume, the correlation is tentative.

TERTIARY INTRUSIVES.

Distribution and Character.

In addition to the Caribou body there are in this area four monzonitic stocks, two of which are very small, and about 50 dikes of diverse compositions. As shown on the geologic map, the stocks are irregular bodies lying along a north-south line through the center of the area; the Caribou stock lies at the middle of this line.

The Eldora stock extends from about one mile south of the Caribou body southward beyond the limit of the area surveyed. It is composed essentially of one kind of rock—a uniformly medium-grained, light-gray monzonite. In some places the rock is porphyroid, and the alignment of the feldspar phenocrysts suggests a flowage structure. Thin-sections show that the monzonite consists principally of plagioclase ($Ab_{80}An_{20}$) and orthoclase. Augite and uralitic hornblende are the most important minor constituents, but the abundance of titanite and apatite in scattered euhedral grains one millimeter in size is noteworthy.

The Lake Isabelle stock in the northern part of the area was not studied in detail, but a brief inspection showed that it is a composite body that consists principally of light monzonite enclosing two mafic masses, one of hornblendized pyroxenite and the other of diorite. The relative age of the mafic masses is unknown, but they are both older than the enclosing monzonite. Typical specimens of the monzonite that forms the bulk of the stock are nearly white, spotted with black mafic minerals. Plagioclase, in grains as large as 4 mm. is the predominant mineral; orthoclase and a few grains of quartz are interstitial to the plagioclase. The dark grains are iron-rich augite, partly altered to hornblende. The abundance of titanite is a distinctive feature.

The contact of the monzonite with the enclosed diorite is exposed just north of the Lake Isabelle outlet. The contact is knife sharp, and apophyses of monzonite cut the diorite, showing clearly that the mafic rock is older. Other exposures afford clear evidence that, like the diorite, the mass of hornblendized pyroxenite is older than the enclosing monzonite. At the northeastern margin of the mass one can see large angular blocks of the ultramafic rock enclosed in monzonite, and apophyses of monzonite cut the ultramafic material. Other apophyses can be seen at the western margin, immediately south of the lake outlet. At some exposures there is a narrow zone between monzonite and ultramafic rock in which the two materials apparently are mixed: The monzonite ten feet from the contact is a light-colored, coarse-grained rock similar to the remainder of the stock; the grains show no parallelism. As one approaches the contact, there is a gradual increase in the amount of mafic material, both in grains and in small lenticular masses. In the marginal dark zone, the mineral grains as well as the many elongate xenoliths are aligned as if by flowage. This dark zone contains about one-third mafic minerals and two-thirds feldspathic; the transition to the dark hornblendized pyroxenite is abrupt.

Megascopically, the ultramafic rock is irregular in texture and color. Parts of the rock consist of greenish pyroxene in

5 mm. grains, with many scattered, larger crystals of black hornblende. Other parts consist almost entirely of coarse black hornblende in grains as much as 5 centimeters long. A few patches contain plagioclase, which is coarse grained. A noteworthy feature of the rock is the abundance of veinlets of black hornblende as much as half an inch thick. These veinlets criss-cross through the greenish, fine-grained pyroxenite portions. Thin-sections show that the fine-grained green material consists almost entirely of pyroxene, with sporadic grains of hornblende. The hornblende grains range from completely solid crystals to large skeletal grains that extend as a mesh through the matrix of smaller pyroxene crystals. All these features point to hornblendization.

Of the two minor stocks between Lake Isabelle and Caribou, the northern consists of monzonite similar to that of the Lake Isabelle mass except that it contains about ten per cent quartz. The other stock consists of coarsely porphyritic monzonite.

The stocks indicate that a variety of magmas invaded the pre-Cambrian rocks, and the dikes of the area indicate an even greater diversity. These dikes have been described by George and Crawford (1908, pp. 23-24) and by Bastin (1917, pp. 49-52). Their distribution is shown on Bastin's map (1917, Pl. 1). Bastin classified them as follows: Biotite diorite, hornblende diorite, porphyritic diorite, andesite, hornblende andesite, hornblende-biotite andesite, hornblende latite, porphyritic monzonite, hornblende monzonite, granite porphyry. The dikes are not large; they range in thickness up to 20 feet and in length up to about four miles. In the area east of Caribou, where they are most numerous, they are closely spaced. This is illustrated by the Boulder County tunnel, which cuts 19 dikes in a distance of 3,200 feet—an average of one every 166 feet. Many of these are small and could not be found on the surface above the tunnel.

Relative Ages of the Intrusives.

Within the area studied there is no evidence for accurately dating the younger intrusives, because they cut only pre-Cambrian rocks. In the published descriptions of the post-Cambrian stocks and dikes in the Front Range it has been generally assumed that all belong to one cycle of igneous activity, and inasmuch as the stocks cut Cretaceous rocks in some places, all of the bodies are classified as Cretaceous(?) and

Tertiary. In some districts a sequence of intrusion has been established on the basis of intersections of stocks or dikes, and attempts have been made to build up a sequence for the entire Front Range by correlation of petrographically similar rocks from separated districts. The most detailed classifications are those presented by Lovering (1935, p. 30) and by Lovering and Goddard (1938), in which the Caribou stock is classed as early Eocene.

Positive evidence of the relative ages of the stocks and dikes was seen only at the margin of the Eldora stock, on glaciated exposures one mile west of Eldora. Small dikes of hornblende monzonite and hornblende andesite are cut by monzonite apophyses of the Eldora stock. There are, furthermore, seams of secondary hornblende in the hornblende monzonite and these are also cut by the Eldora apophyses. Inasmuch as seams of secondary hornblende are notably abundant in the monzonite of the Caribou stock, but are absent in the Eldora stock, it seems justifiable to consider these relationships as additional evidence that the Caribou stock as well as the hornblende monzonite dikes belong to an older period of intrusion.

Summary.

The Tertiary intrusives show several features pertinent to the problems of the Caribou stock which may be summarized as follows:

(1) The diverse dikes and stocks show that the pre-Cambrian rocks of the area have been invaded by a number of magmas that differed in composition.
(2) The scant evidence found indicates that the Caribou stock, as well as hornblende monzonite and hornblende andesite dikes, are older than the other stocks.
(3) Both the Caribou and Lake Isabelle stocks are composite bodies, in which there are older masses of mafic rocks enclosed in younger monzonite.
(4) The Caribou stock is unique among the Tertiary instrusives of the area in that it contains masses of titaniferous magnetite.

DETAILED GEOLOGY OF THE CARIBOU STOCK.

Distribution and Relative Ages of the Main Rock Types.

The Caribou stock is an irregular body, roughly equi-dimensional, with a total area of four square miles, half of which is

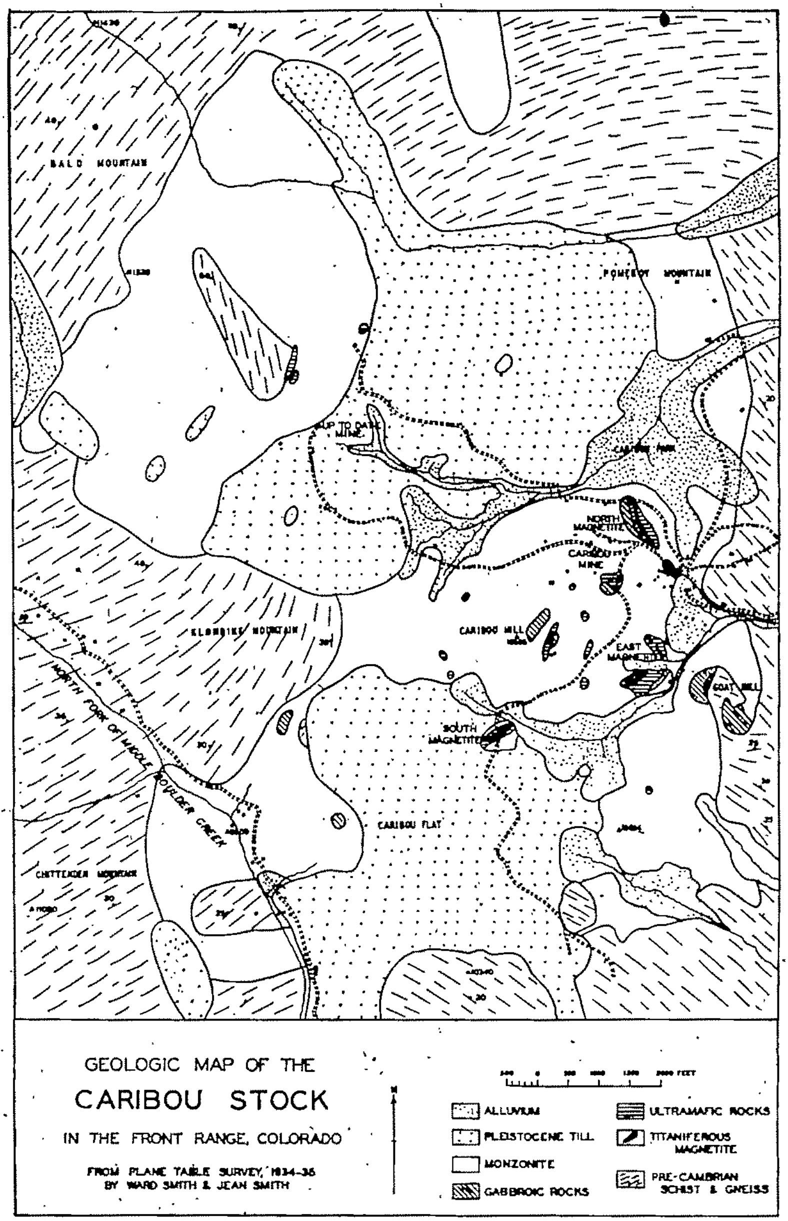
BALD MOUNTAIN
POMEROY MOUNTAIN
UP TO DATE MINE
CARIBOU PARK
NORTH MAGNETITE
CARIBOU MINE
CARIBOU HILL
EAST MAGNETITE
GOAT HILL
KLONDIKE MOUNTAIN
NORTH FORK OF MIDDLE BOULDER CREEK
SOUTH MAGNETITE
CARIBOU FLAT
CHITTENDEN MOUNTAIN
GEOLOGIC MAP OF THE
CARIBOU STOCK
IN THE FRONT RANGE, COLORADO
FROM PLANE TABLE SURVEY, 1934-35
BY WARD SMITH & JEAN SMITH
N
500 0 500 1000 1500 2000 FEET
ALLUVIUM
PLEISTOCENE TILL
MONZONITE
GABBROIC ROCKS
ULTRAMAFIC ROCKS
TITANIFEROUS MAGNETITE
PRE-CAMBRIAN SCHIST & GNEISS

Plate III.

covered with alluvium. (See geologic map, Pl. 3.) It is a composite intrusive that consists chiefly of biotitic augite monzonite enclosing small masses of gabbroic and ultramafic rock. Within the ultramafic masses, which constitute about five per cent of the stock, there are bodies of titaniferous magnetite. In addition to these principal types of rock there are several minor varieties: dikes of aplite, lamprophyre, and monzonite porphyry, and one irregular mass of pegmatite. All of these minor varieties are intruded into the biotitic augite monzonite. The stock is cut by a number of small veins, some containing hematite and others containing gold-silver ores and their associated sulphide and carbonate minerals.

Although the total volume is small, the number of ultramafic masses in the stock is a striking feature. About 25, which range in size from a few feet up to a maximum of a thousand feet, were studied in the field. Of these, only the larger bodies are plotted on the map. Gabbroic masses are less abundant than the ultramafic bodies; eight are represented on the map.

The distribution of the ultramafic and gabbroic bodies in the monzonite is highly irregular and apparently unsystematic. Areally, the mafic masses are scattered from the center to the periphery; two ultramafic bodies at the stock margin lie between monzonite and schist, and there is one marginal mass of gabbro. Although most of the exposed masses are concentrated near the eastern part of the stock, there is no uniformity of pattern or alignment in the areal distribution. Furthermore, the topographic relief permits observation that the vertical distribution is also irregular. It can also be seen from the map that the position of the gabbroic bodies with respect to the ultramafic rocks on the one hand and the monzonite on the other is unsystematic. Gabbroic rock accompanies each of the larger ultramafic masses and some of the smaller ones; it was not found with a few small bodies. The gabbro adjacent to the ultramafic rock is always at the ultramafic periphery, but in no case does gabbro form a zone completely encircling a mass of ultramafic rock and separating it from monzonite. Some gabbroic bodies are isolated from ultramafic material, and others contain only scattered fragments of ultramafic rock a few inches in size. The ratio of ultramafic to its associated gabbroic rock is different for each mass.

The field examination showed that all the rocks in the composite stock are not of the same age. The age relationships are particularly well shown on the east side of North Fork

Valley, south and southeast of Klondike Mountain, where the steep, bare rock walls provide the largest areas of continuous exposure. In this portion of the stock the predominate rock is biotitic augite monzonite, which encloses masses of gabbro ranging in size from a few inches up to more than a hundred feet. Apophyses of monzonite cut the gabbro. Enclosed in the gabbro and also in the monzonite are a few angular fragments of pyroxenite, some of which enclose fragments of schist.

Further evidence of the relative ages can be seen at the contacts of one rock type with another. The best exposure of the contact of monzonite and ultramafic rocks was seen on the side of Bald Mountain, above the Up to Date mine. The contact is knife sharp, there are small apophyses of monzonite that cut the ultramafic rock, and the monzonite encloses isolated angular fragments of the dark material. At monzonite-gabbro contacts the transition is also abrupt rather than transitional. South of Klondike Mountain the rock composition changes within a fraction of an inch. Although the contacts of monzonite with gabbro and monzonite with ultramafic rock are sharp, contacts of gabbro with ultramafic rocks appear gradational because of the intimate admixture of gabbro and ultramafic fragments. A contact of ultramafic rock with gabbroic material can be seen in a prospect pit on the East Magnetite deposit. A zone of gabbro contains fragments of pyroxenite, which increase in number and size toward the solid pyroxenite. This is essentially an intrusion breccia. The appearance of gradation is enhanced by abundant secondary hornblende. Prospect pits at the margin of the North Magnetite Deposit also afford evidence of the same relationship, and similar mixed pyroxenite and gabbro can be seen at the Caribou Flat magnetite deposit as well as at the deposit east of Caribou benchmark.

At these exposures the relative ages of the main rock types are clearly shown: the ultramafic masses comprise the oldest rocks, the gabbroic masses are next younger, and the monzonitic rocks are still younger.

The minor intrusives comprise such a small part of the stock that they require only brief mention. Although monzonite porphyry is not well exposed, the distribution of float indicates that it forms a narrow elongate mass surrounded by biotitic augite monzonite. An irregular mass of pegmatite, exposed about 1,500 feet northeast of the Caribou benchmark, is enclosed in biotitic augite monzonite, but direct evidence that the pegmatite is younger is scant: a single block of monzonite was seen enclosed in pegmatite. Neither rock shows chilling or contact metamorphism. Only two dikes of lamprophyre were seen; they cut biotitic augite monzonite, east of the gabbroic rock of the East Magnetite deposit. Aplite forms numerous thin dikes, rarely more than an inch thick, which cut members of the pyroxenite, gabbro, and monzonite groups; none were seen in the pegmatite, monzonite porphyry, or lamprophyre. Inasmuch as the minor intrusives cut the biotitic augite monzonite, the group comprises the youngest rocks in the stock. Their relative ages are uncertain.

Petrography of the Stock.

All the main rock types are characterized by the presence of augite that contains a small amount of uralitic hornblende at the periphery of grains or as intergrown shreds. In the biotitic augite monzonite such hornblende might be considered a product of late-magmatic reaction. In the augite gabbro and pyroxenite, the uralitic hornblende may have formed either by late magmatic reaction or as a result of contact metamorphism during the intrusion of the younger magmas. Some parts of the augitic main rock types are so thoroughly altered that hornblende is the predominant mineral. (Inasmuch as these rocks are products of hornblendization, they are not to be regarded as separate igneous intrusions, and therefore do not enter into the age sequence.)

There is good field evidence that part of the hornblendization is post-magmatic. Nearly every outcrop shows many thin veinlets or "seams" of black hornblende. Most of these veinlets are less than an eighth of an inch thick, but they are prominent because they follow planes of weakness along which the rock tends to split, so that many angular blocks show black hornblende-coated joint surfaces. At a representative exposure the veinlets are a few inches to three feet apart. Measurement of the attitudes of the seams at several outcrops showed that they lie in a dozen or more directions; they have no predominant position and do not follow a simple system of fractures. They appear in ultramafic, gabbroic, and monzonitic rocks, and in aplite, but none was seen in monzonite porphyry, hornblende pegmatite, or lamprophyre. The character of the seams differs slightly with the kind of rock in which they occur: In the monzonitic rocks the seams are thin and narrow, with the margins sharply defined; in the gabbroic rocks they are thicker and the margins irregular; in the ultramafic rock they are thickest, and the material of the seams grades into the adjacent rock. Hornblendization of adjacent grains of augite, the primary mafic mineral in the rocks, produces the diffuse appearance of the seams in the gabbroic and ultramafic rocks. The augite of the monzonite is affected in the same way, but the primary grains are not sufficiently abundant to produce the gradational effect. The hornblende veinlets can be classed definitely as a post-magmatic feature of the stock rather than "late-magmatic," because they obviously formed in fractures that can have developed only in solid rock.

In addition to the hornblendization, biotitization has probably played a part in the history of the stock, although there is some doubt on this point. The evidence for biotitization is: (1), the occurrence of irregular patches or clusters of biotite in pyroxenite at the East Magnetite deposit, at the Up to Date mine, and at the small mass of pyroxenite east of the Caribou benchmark; and (2), the exposures of small (20 feet, maximum width) areas of ultramafic material containing so much biotite that specimens crumble in one's hand. The relationship of this rock to the surrounding rocks could not be studied closely because even in the moderately recent prospect pits it is disintegrated. Its composition is so abnormal that one is justified in tentatively classifying it as an alteration of the pyroxenite rather than as a primary rock.

The hornblendization and biotitization have formed masses of distinctive rocks. Other alterations that had a less marked effect also can be seen in all rock types: Epidotization is widespread; and adjacent to veins the rocks are intensely altered, chiefly by sericitization, silicification, and carbonation.

Primary Ultramafic Rocks and Titaniferous Magnetite.

The ultramafic masses of the stock contain, in addition to the titaniferous magnetite bodies, which are their chief feature, a variety of other rocks: Pyroxenite, olivine pyroxenite, serpentine rock, biotite pyroxenite, porphyroblastic hornblende pyroxenite, hornblendite, biotite hornblendite, biotitite (?). The pyroxenite is by far the most important of these rocks not only because it contains the concentrations of iron ore, but because it forms the largest part of each ultramafic mass and is believed to be the primary rock from which other varieties were derived by alteration.

Pyroxenite. Typical pyroxenite is a heavy, compact, dark greenish gray, evenly granular phanerite, composed principally of pyroxene in 2- to 3-millimeter grains. Most hand specimens contain a few flakes of black biotite and elongate prismatic crystals of hornblende. Invariably one can distinguish on fresh surfaces the steely luster of magnetite. On the weathered surfaces of iron-rich specimens the magnetite is dull black and commonly forms a reticulate meshwork which stands in slight relief above the rust-stained gray of the weathered-out silicate grains. Many specimens also contain small grains of pyrite and epidote; particles of white plagioclase are rare.

Microscopically, the textural relationship of the opaque minerals to the silicate grains is of particular interest, because it is an important factor in the interpretation of the origin of the iron oxide bodies. Most of the opaque material is interstitial to the silicate grains and appears to form a cement or matrix enclosing the silicate minerals. Every thin-section shows also opaque grains within the augite, but such grains are subordinate in number and volume to the interstitial magnetite and ilmenite. The interstitial position is obvious even in those specimens that contain as little as ten per cent of the opaque material. The augite grains are short, subhedral prisms which rarely show completely idiomorphic crystal boundaries; typically the margins adjacent to titaniferous magnetite are irregular (but this irregularity in form is not greater than that shown by grains of augite enclosed in plagioclase in the gabbros and monzonites of the stock). Most isolated grains of augite enclosed in magnetite, however, are markedly irregular in outline. No veinlets of magnetite cutting pyroxene grains were seen in thin section. In magnetite-rich specimens—for example, one with 40 per cent of opaque grains—the evidence that the ilmenite and magnetite solidified after the silicate grains is most convincing, for thin-sections of such specimens show many areas of opaque material within which lie isolated grains of augite.

The other minerals in the pyroxenite are of minor importance. The hornblende has the same textural relationships to the opaque minerals as the augite from which it is derived. Hornblende appears in the thin-sections as shreds or patches intimately intergrown with augite. Small flakes of biotite are evenly scattered through the rock, some enclosed in augite, others interstitial to augite grains. A few fairly euhedral apatite grains are scattered through both magnetite and augite.

Small grains of green spinel (pleonaste ?) are invariably found with the magnetite. Among the secondary minerals, chlorite and epidote are developed at the expense of biotite, and sericite from plagioclase; the pyrite, carbonate, and quartz, of which the last two are rare, form small irregular grains.

Olivine pyroxenite. The relationships of the olivine pyroxenite to the other ultramafic rocks is obscure because the olivine cannot be identified in the field. The mineral is rare; it was found in only one thin-section, of a rock from the North Magnetite deposit. Material richer in olivine was found at the ultramafic mass south of Caribou by Bastin, who. classed the rock as magnetite peridotite (1917, p. 47). Megascopically, the rock is similar to the pyroxenite except that on a fresh surface one can see with a hand lens a little green serpentine of waxy luster. Microscopic examination shows that the olivine and the serpentine derived from it makes up about ten per cent of the rock. Many of the olivine grains are completely serpentinized, others are merely cut by serpentine veinlets, and a few are unaltered. No serpentinized augite was seen in thin-section. Texturally, this olivine pyroxenite is similar to the olivine-free varieties.

Serpentine rock. Some specimens obtained from the North Magnetite deposit and the East Magnetite deposit are classed as magnetite-rich serpentine rocks. These rocks are metasomatic derivatives of the pyroxenite and therefore properly belong in the next section, but they are included here because they are rich in titaniferous magnetite. Megascopically, these rocks are similar to olivine pyroxenite, but thin-sections showed that they consist almost entirely of serpentine, magnetite, and ilmenite. Thin-sections also show that they have a texture similar to that of the pyroxenite except that aggregates of serpentine replace pyroxene and olivine grains. The serpentine aggregates are similar to the silicate grains in size and shape. They contain no relict structures, so that one cannot be certain whether the serpentine is derived from olivine, or pyroxene, or both. The fact that in the olivine pyroxenites only olivine was serpentinized suggests that all. the serpentine is derived from olivine. However, olivine is a rare constituent in the ultramafic rocks, and to conclude that there were parts of the ultramafic bodies in which olivine was the only silicate mineral seems unwarranted. Serpentine may form from pyroxene as well as from olivine, and it seems probable, therefore, that the serpentine rocks are derived from olivine pyroxenite.

The thin-sections of these rocks afford evidence that part of the magnetite is secondary. Two features show that this is the case: First, at the margins of some rounded serpentine areas (serpentinized grains of olivine or augite) there are intergrowths of magnetite and fibrous serpentine. These intergrowths are comb-like structures composed of serpentine fibers alternating with equally slender, parallel magnetite grains. Second, the rock is cut by many veinlets 1 to 2 millimeters thick and a few centimeters long in which the same fibrous intergrowth of serpentine and magnetite appears. The fibers are normal to the vein walls. These veinlets of serpentine and magnetite can be seen on polished surfaces as well as in thin-section. The intergrowths are undoubtedly secondary, but it is uncertain whether the two minerals formed contemporaneously or whether one replaced the other.

Titaniferous magnetite. Examination of the richest iron oxide deposits showed that all of them are essentially the same; the largest body, at the North Magnetite deposit, is typical. The ultramafic body is a composite mass of pyroxenite and gabbro that extends N. 60° W. for about 1,000 feet, and has a maximum width of about 300 feet. A central zone of magnetite-rich material 15 to 20 feet wide extends the length of the pyroxenite. A smaller mass of pyroxenite with a central zone of magnetite lies a short distance southeast of the main mass, separated from it by monzonite. The similarity in character and in orientation suggests that the two masses were once continuous.

Natural exposures are not good, but prospect pits show the following relationships: (1), the central portion of the magnetite zone consists of veinlets or dikelets of nearly pure titaniferous magnetite, which range in thickness from one to four inches; these veinlets interlace to form a network which in places is almost solid titaniferous magnetite. (2), the pyroxenite adjacent to the network of veinlets contains much disseminated magnetite; exposures are not adequate to show whether or not the amount of magnetite progressively decreases away from the zone of veinlets. (3), in addition to the titaniferous magnetite there are many very small (1 mm. thick) veinlets of serpentine in the pyroxenite. Although the exposures show that the pure titaniferous magnetite as well as the magnetite-serpentine intergrowths are later than the enclosing magnetite-rich pyroxenite, they seem to afford no positive evidence as to whether the pure magnetite formed by solidification as dikelets or by precipitation as veinlets. This point will be discussed later, with the origin of the rocks of the stock. It should be pointed out here that veins of titaniferous magnetite, as well as veinlets of serpentine and magnetite, are restricted to the pyroxenite. None was found in gabbroic or monzonitic rocks, and no specimens of gabbro or monzonite were seen that contained sufficient disseminated magnetite to justify classing them as magnetite-rich rocks. This indicates that, when the origin of the titaniferous magnetite is considered, only its relation to the associated ultramafic rocks need be regarded as an essential part of the problem; the gabbroic and monzonitic rocks are later intrusives.

As the magnetite-rich material has a relatively high resistance to disintegration, the surface of the ground is covered with fragments of float. This surface coating prevents accurate mapping of the distribution of magnetite. Fortunately, the results of a magnetometer survey are available for the largest body, the North Magnetite deposit. The magnetometer work showed that the magnetite is unequally distributed: Nearly all of it lies in a definite zone as suggested by surface exposures, but within the zone it is in "bunches" and there are outlying patches of magnetite-rich material near the zone, but not in it (Heiland, Henderson, and Malkovsky, 1929, Fig. 7).

Microscopic examination of polished surfaces showed that the veinlet material is mostly magnetite in 0.5 millimeter grains, with a small amount of ilmenite in grains of equal size. Even under an oil immersion lens one can see in the magnetite no regularly arranged lamellae or plates of ilmenite of the "ex-solution" or "unmixed" type. There are some lines of minute inclusions in the magnetite grains, but these are probably spinel, a mineral that can be seen in thin-sections. Etching of the polished surface with stannous chloride brings the lines of inclusions into sharp relief. Each line consists of round "dots" and short, rather thick "dashes" similar to the magnetite inclusions identified by Warren (1918, pp. 429-30) and others as spinel. The magnetite intergrown with serpentine in veinlets does not react with the stannous chloride reagent used on polished surfaces to distinguish magnetite and ilmenite. Probably it contains enough of some other element (titanium ?) to affect its behavior toward this reagent. That the mineral is magnetite seems certain: Its color is the same as that of the other magnetite in the rock, it is equally hard, and quite isotropic. Isolated grains are strongly magnetic. Chromite has similar physical properties excepting magnetism, but a chemical test of isolated material showed that it contains no chromium. Bastin states that chromium was absent in all specimens that he tested (1917, p. 49).

Metasomatic Derivatives of Pyroxenite.

Biotite pyroxenite. All of the pyroxenites contain uralitic hornblende and sporadic flakes of biotite. In some small masses the biotite is conspicuous and the rock can be classed as biotite pyroxenite. Excellent specimens of this kind can be obtained from a small mass on the hillside above the Up to Date mine or from another mass on the east side of Klondike Mountain. Megascopically, the rocks are 5 mm. grained and evenly granular. Black biotite is evenly distributed in a matrix composed chiefly of green pyroxene with a small amount of gray plagioclase. Thin sections show that the biotite is interstitial to augite and plagioclase; the texture suggests that the biotite is a primary mineral, rather than secondary. In specimens from east of the Caribou benchmark, however, the biotite occurs as clusters of 1 or 2 centimeter flakes in a matrix of finer-grained pyroxene. Thin-sections show that much of this coarse biotite is in skeletal poikilitic flakes that extend through a mosaic of augite. This suggests, although it does not prove biotitization. The minor constituents of these rocks are apatite, zircon, titanite, quartz, sericite, and epidote.

Biotitite(?) is exposed in one prospect pit near the southwestern margin of the North Magnetite deposit and in another in the southern part of the East Magnetite deposit. The rock contains so much biotite that it crumbles into grains, and therefore specimens suitable for study could not be obtained. Bastin reported the same material, and estimated that biotite comprised 50 per cent of the rock. If the rock is of igneous origin, the magma from which it formed must have been unusual. Most probably the rock was formed by biotitization of pyroxenite.

Porphyroblastic hornblende pyroxenite, found only at the Up to Date mine, is one of the most striking of the ultramafic varieties because of its unusual texture. The rock consists of 1 to 3 centimeter subhedral crystals of black hornblende in a fine-grained matrix of green pyroxene and black biotite. The large hornblende crystals make up a tenth to a fifth of the rock. In thin-section they are seen to be poikiloblastic crystals that contain grains of the other constituents of the rock:

augite, biotite, apatite, and some magnetite. In the thin-sections one can see all stages of development of the large hornblende crystals, from an initial stage in which hornblende is merely a spongiform, optically continuous network that extends through the matrix of pyroxene and biotite, through stages in which the hornblende is more and more predominant, to completely grown hornblende crystals that are solid except for inclusions of magnetite and apatite. This gradational series is interpreted as evidence that the large crystals developed metasomatically in solid pyroxenite.

Hornblendite. Excellent specimens of hornblendite can be found on the dump of the Up to Date mine and also on the hillside above the mine. Similar rock can be obtained at the small magnetite deposit east of Caribou benchmark and at one prospect pit on the East Magnetite deposit. Bastin's petrographic description of material from the Up to Date mine dump is excellent:

> "Green hornblende in prismatic crystals as much as 1.5 centimeters in length is the principal component. The crystals are oriented in all directions. The hornblende appears to be original rather than an alteration product after pyroxene, but there may be some doubt on this point. The mineral is perfectly fresh in appearance. Plagioclase is present in small amounts and has the composition of labradorite near $Ab_{40}An_{60}$. The minor constituents are biotite, apatite, magnetite, and titanite. Magnetite forms anhedral crystals and constitutes perhaps five per cent of the volume of the rock; adjacent to it or intergrown with it are small amounts of pyrite, which appears to be original. Titanite is present in a few scattered grains" (1917, p. 46).

Thin-sections show epidote, chlorite, and sericite, the presence of which suggests that the rock has been slightly altered hydrothermally, and it is possible that the pyrite is also of hydrothermal origin. Pyroxene, although rare, is present.

Biotite hornblendite. Hornblendite grades into biotite hornblendite. A typical specimen from the Up to Date mine dump is a black, coarsely granular (1 cm.) phanerite, composed of hornblende and biotite in about equal amounts. Microscopic examination shows that texturally the rock is notable for the intergrowth of large grains of hornblende and biotite, and for the abundance of large euhedral apatite crystals. There are scattered, irregular grains of pyroxene. Minor constituents are hydrothermal derivatives of the principal minerals.

The hypothesis that hornblendization and biotitization were related to the origin of the magnetite bodies was entertained during the study. This possibility is opposed, however, by the distribution of the altered rocks. There is no relationship between degree of hornblendization and amount of magnetite. The ultramafic mass that encloses the North Magnetite deposit is chiefly pyroxenite and no greatly hornblendized rocks were seen there. At the East Magnetite deposit, also, there is no highly hornblendized pyroxenite, and biotite-rich material appears at only one place. At the small magnetite deposit east of Caribou benchmark the pyroxenite contains hornblende porphyroblasts and prominent clusters of biotite, but the veinlets of magnetite are small. At the Up to Date mine the ultramafic masses comprise the most thoroughly hornblendized material in the stock, but the associated pyroxenite is not rich in magnetite. The masses of biotite found near some of the magnetite bodies cannot be taken as evidence that biotitization accompanied the formation of magnetite, because: (1), no such material occurs at other magnetite bodies; (2), one mass of similar biotite enclosed in monzonite northwest of Caribou stock has no associated magnetite, and; (3), masses of moderately biotitic pyroxenite found at several places contain no unusual amount of magnetite and ilmenite. In short, the size of the hornblendic and biotitic masses is not proportional to the size of the titaniferous magnetite bodies and their position has no apparent relation to the magnetite bodies. The field evidence, therefore, indicates that hornblendization and biotitization are not features genetically related to the magnetite. This is also indicated by microscopic evidence that the amount of magnetite is not proportional to the amount of hornblende or biotite.

Optical Properties of the Minerals in the Ultramafic Rocks.

The optical properties of the silicate minerals in the pyroxenites are of interest because they give information about the chemical composition. The principal silicate minerals are olivine, pyroxene, and biotite. The relationships between optical properties and chemical composition are well established for olivine, but are imperfectly known for the other two minerals. However, in the problem of the origin of the iron oxide deposits the two elements of most significance are iron and titanium, and the presence of a large amount of these elements has characteristic effects on the optical properties of these minerals.

The one thin section that contains olivine shows, in well-centered interference figures, an optic bar too straight for determination of the sign; the value of 2V, therefore, is near 90°. This indicates that the olivine is a magnesian variety, in which the iron content is low. Regarding the amount of titanium, the optical properties show nothing.

The pyroxene is apparently the same in all the ultramafic rocks. In thin-section the mineral is pale greenish gray and non-pleochroic. Optically, it is biaxial positive, with 2V near 60°, and the extinction angle for gamma against "c" is 41°. The birefringence could not be estimated accurately because for these ultramafic rocks the thickness of each thin-section was not known. Many interference figures were examined in an attempt to ascertain the character of the dispersion, which is of especial interest for two reasons: First, in favorable cases differences in the dispersion enable one to distinguish augite from diopside. Second, a pronounced dispersion would indicate the presence of titanium in the pyroxene. It was found that the pyroxene in these rocks has almost no dispersion, and therefore this property affords no basis for choosing between augite and diopside as a name for the mineral. The slight dispersion indicates that the pyroxene contains but little titanium. Jennings presented the following analysis of the mineral (1913, p. 24):

	Computed Analysis	*Analysis of Separated Material*
SiO_2	53.82	54.24
Al_2O_3	6.93	7.03
FeO	3.90	3.97
CaO	21.62	21.41
MgO	12.85	12.65
Na_2O	0.88	0.87
K_2O	Tr.	Tr.
	100.00	100.17

Although Jennings used the name "diopside" for the mineral, the presence of alumina as shown by the analysis makes augite seem preferable. Jennings' analysis does not record the amount of titanium; it shows that the amount of iron is not high, and that all the iron is ferrous. The optic properties likewise indicate that the augite is not rich in ferric iron—augites that contain much ferric iron are colored, whereas this is pale. Furthermore, a high content of iron and titanium imparts pleochroism, which is lacking in the augite of these rocks.

The biotite of the ultramafic rocks is pleochroic brown and yellow—it does not have the red or strong red-brown color of titaniferous biotite. Measurement in immersion oils showed little difference in the biotites from several varieties of rock, the value of the index of gamma ranging from nearly equal to 1.63 to slightly above 1.64. These values are typical of common biotite.

From the optical properties and chemical analysis, therefore, one can conclude that although the mafic silicates contain iron and perhaps some titanium, the amount of these elements is small. Certainly the olivine and pyroxene do not belong among the iron-rich members of their respective series, and neither pyroxene nor biotite is highly titaniferous.

Biotite Augite Gabbro and Metasomatic Derivatives.

The gabbroic rocks show less diversity than the ultramafic rocks: Three varieties can be distinguished: Biotite augite gabbro, hornblendized gabbro, porphyroblastic hornblende gabbro. Of these the first is the most common variety, and from it the other two were derived by metasomatic alteration.

Biotite augite gabbro. Megascopically the gabbro is an evenly granular 2 to 4 mm. phanerite composed of about equal parts greenish gray pyroxene and light feldspar; the amount of biotite ranges up to a maximum of 15 per cent. Most specimens show a few grains of epidote and pyrite. Thin-sections of typical specimens show that hornblende derived from augite is present. Hypersthene is a rare constituent; it was seen in only one thin-section. The common hydrothermal alteration products—pyrite, sericite, chlorite, epidote, and in a few rocks quartz and carbonate—are present. Texturally, the rock is hypidiomorphic, coarsely granular. The fabric is directionless in most thin-sections, but a few show a parallelism of the plagioclase laths.

Hornblendized gabbro. Examples of partly hornblendized gabbro can be obtained from the same outcrops that provide augite gabbro specimens. Megascopically, the hornblendized material is darker in color, and the ferromagnesian grains are distinctly black, whereas the augitic gabbro is lighter gray in general color, and the grains are gray green. At many outcrops one can see veinlets of hornblende in the gabbro, and adjacent to these veinlets the hornblendization of the rock is usually greater than at a distance.

In thin-sections one can see all gradations from the augitic specimens, in which the augite is little altered, through a series of rocks in which hornblende is more and more abundant. Quantitative measurements show that the amount of hornblende is inversely proportional to the amount of pyroxene. In the augitic rocks of this series, the hornblende is nearly absent or, if present, is restricted to the periphery of the augite grains. In intermediate rocks the thin-sections show an intimate intergrowth of hornblende and augite in grains that retain the augite prismatic forms. In the hornblende-rich gabbro, only small residual shreds of augite are seen. The hornblende in such rocks exceeds the limits of the former augite crystals; the amount of hornblende is greater than the former augite content, and consequently the rock is appreciably darker than augitic varieties of the gabbro.

Fine examples of strongly hornblendized gabbro are afforded by the outcrops on the south side of Klondike Mountain, at the western edge of the stock. It can be seen in the field that the rock is not homogeneous, but that the black hornblende is unequally distributed so that the surface, instead of being uniformly dark in color, is mottled. Microscopic examination confirms the conclusion that the hornblende is irregularly distributed. In a large thin-section one can see lighter parts where hornblende is relatively scarce, and darker parts where hornblende is abundant. In the lighter portion there are augite crystals which are only slightly hornblendized. In the darker portion augite is relatively scarce, the few grains present being small, irregular in outline, and enclosed in hornblende. These small augite grains are clearly unaltered residuals of larger grains, and one can conclude that the hornblende in the rock formed at their expense. Much of the hornblende, however, must have been introduced metasomatically to form the dark patches that contrast with the light patches of original augitic rock. Apatite and titanite, although minor constituents, are conspicuous in thin-sections. The amount of these minerals is unusually high for the Caribou stock, and possibly they were introduced into the rock with the hornblende.

Examination of gabbro that contains ultramafic xenoliths shows that the principal effect of the magma on the enclosed material was a mechanical disintegration. Mineralogically, the augite of the xenoliths appears to be unaltered except for hornblendization. The amount of hornblende developed, however, is always proportional to the degree of secondary hornblendization of the enclosing gabbro, and therefore is not a product of metamorphism by the gabbroic magma. One thin-section of a gabbro that contains pyroxenite xenoliths shows not only the contact of the two rocks, but also a hornblende "seam" that extends across the contact, through both rocks. The "seam" is actually a zone with diffuse gradational boundaries, within which the augite grains of both gabbro and pyroxenite are hornblendized. Within the gabbro portion of the slide one can see that the seam represents not only the hornblendization of augite grains, but also an addition of considerable hornblende.

Porphyroblastic hornblende gabbro. The distinctive feature of this rock is the presence of abundant large (as much as one centimeter) crystals of hornblende. These are enclosed in an evenly granular matrix of fine grain size that resembles the hornblendized gabbro just described. Microscopic examination indicates that this rock is essentially the same as the "hornblende gabbro" described by Bastin (1917, pp. 45-46), who considered the hornblende primary and therefore described the texture as porphyroid, rather than porphyroblastic. The rock is interpreted in the present report as a hornblendized gabbro, analogous to the porphyroblastic hornblende pyroxenite of the ultramafic group.

Optical Properties of the Minerals in the Gabbroic Rocks.

Among the gabbroic rocks the mineral of chief interest is hornblende, of which two varieties can be distinguished on the basis of differences in their pleochroisms: In one, X is pale yellow, Y is dark green, Z is blue green. In the other, Z is olive green. Both have an extinction angle of 18°. Most, but not all, of the hornblende interpreted as uralitic because it is intimately intergrown with augite is of the olive green variety. Some of the blue green type is intergrown with augite, but it is notably abundant in the much-hornblendized mottled gabbro. Inasmuch as this rock appears to have been enriched in hornblende, it is probable that the blue green variety is an introduced hornblende. Thin-sections of a gabbro specimen from the Up to Date mine show hornblende grains in which the color grades from olive green at the center to blue green at the margin. This suggests that the blue green variety is later than the other, although not necessarily a secondary mineral. Only the blue green variety appears in the hornblende veinlets, which are undoubtedly secondary. The evidence seems to support the conclusion that most, if not all, of the blue green hornblende is secondary, whereas the olive green variety is older. Whether the older hornblende is a product of magmatic reaction and therefore primary, or formed during a hornblendization that preceded the development of veinlets of hornblende, is uncertain.

Monzonitic Rocks.

Biotitic augite monzonite. Megascopically, the biotitic augite monzonite is a gray, evenly granular 4 mm. phanerite composed of about four-fifths feldspar and one-fifth dark minerals. The chief dark mineral is augite, but biotite forms as much as ten per cent of the rocks. Under the microscope the fabric of typical specimens is seen to be hypidiomorphic and nearly uniformly granular. Plagioclase ($Ab_{70}An_{80}$), the chief felsic mineral, is in subhedral to euhedral lath-shaped grains. Most of the orthoclase is in small grains, interstitial to the plagioclase and mafic minerals, but a few larger grains are poikilitic, enclosing small laths of plagioclase and mafic minerals. Under highest magnification one can distinguish faint lamellae in the orthoclase, which suggest that it is cryptoperthitic. The chief mafic mineral is pale gray, non-pleochroic augite. Most augite grains have intergrown or marginal hornblende. The biotite grains are partly chloritized. Microscopic examination shows that the rock has much more plagioclase than orthoclase and therefore differs considerably from typical monzonite, in which the amounts of plagioclase and orthoclase are approximately equal. This was recognized by Jennings, who classified the rock as an "orthoclase-biotite gabbro in preference to calling it a monzonite, on account of the predominance of the plagioclase" (1912, p. 21). In Bastin's report the same rocks are classified as monzonite and quartz monzonite, and in addition Bastin reported an olivine monzonite. In order to avoid confusion with the Caribou rocks that are distinctly gabbros, the usage of Bastin is followed in the present report, and the rocks intermediate in composition between typical monzonite and gabbro are classed as monzonite.

Facies of monzonite. Small masses of monzonite that differ from the predominant type in grain size and fabric, but are composed of the same minerals in nearly the same proportions can be seen in several places. At their contact such masses grade into the principal rock. The most prominent of these minor facies is one distinguished by the presence of large poikilitic flakes of biotite. Although found in patches throughout the stock, the best specimens appear along the road at the northern edge of Caribou townsite. Megascopically, the rock is like the common biotite augite monzonite except that it has a platy structure, which is emphasized by the subparallel arrangement of the biotite flakes. On surfaces parallel to the platy structure the rock appears mottled because of the abundance of the conspicuous 1 to 2 centimeter flakes of biotite. Fractures across the grain show that the flakes are thin, and the mineral forms only a small part of the volume of the rock. Thin-sections show that the tabular grains of feldspar share the subparallel arrangement of the large biotite flakes. This parallelism, however, is well developed only near the margin of the stock.

Two small masses that differ from the biotitic augite monzonite in composition as well as in texture are exposed in the saddle between Caribou Hill and Klondike Mountain. The contacts of these masses are not exposed, and their relationship to the surrounding biotitic augite monzonite is uncertain. They are composed of bluish gray, 5-millimeter grained, evenly granular rock, which is about two-thirds feldspar and one-third dark minerals. A distinctive feature is the presence of nearly equidimensional pyroxene prisms; the prisms are nearly as thick as they are long, and cross-sections are almost quadratic in shape. The rock differs from the common monzonite in having less orthoclase and more quartz; thus it should be close to diorite. The rock is considered to be a facies of the biotitic augite monzonite rather than as a minor variety among the rocks of the stock because: (1), it has the same kinds of minerals, and (2), except for relatively low orthoclase and high quartz its mineral composition is much the same as that of the more common rock. It is noteworthy that, although the monzonite shows considerable range in texture and some parts differ in composition from the chief type, these differences are not related to the gabbroic and ultramafic masses.

ORIGIN OF THE CARIBOU ROCKS.

The early study of the stock by Jennings was devoted chiefly to the pyroxenite-magnetite masses. As a result of this examination, Jennings concluded that these masses were dikes:

> "The inference is that the origin of the dike was in a deep-seated segregation of ferro-magnesian minerals and magnetite, due to a differentiation from the gabbro magma, and that its composition is essentially the same as that of the parent basin" (1913, p. 25).

It is clear that Jennings considered the ultramafic masses to have formed from a magma; on the same page he refers to "the original dike-magma." He concluded that the pyroxenite-magnetite magma was intruded into the "gabbro" (monzonite) of the stock. Jennings observed the concentration of magnetite in the central parts of the ultramafic masses, and also the presence of highly biotitic masses associated with the pyroxenite. His explanation was as follows:

> "The later rearrangement of the minerals of the dike, due to slow cooling under a great mass of superimposed rock, has partly concentrated the magnetite near the center and the biotite along the walls" (1913, p. 25).

The distribution of the biotite is more irregular than Jennings's statement implies. Biotite-rich rock was found in small masses and only in a few places; its erratic distribution is believed to be due to its secondary, metasomatic origin. According to the present study the magnetite is concentrated in zones which are zones of fissures, but the ultramafic masses are older than the more feldsic rocks of the stock, and are not dikes intruded into the monzonite.

The salient facts about the pyroxenite and the titaniferous magnetite are as follows:

1. The pyroxenite consists of augite, magnetite, ilmenite, olivine, and spinel. The augite and olivine are low in iron and relatively high in magnesium.
2. The chief textural feature of the pyroxenite is the interstitial position of magnetite and ilmenite, which surround and enclose the silicate grains.
3. Much magnetite and ilmenite is in veinlets or dikelets which are concentrated in long and narrow zones within the pyroxenite masses.
4. Spinel, in the form of minute, regularly arranged grains, is intergrown with the interstitial magnetite in the pyroxenite as well as with the magnetite in the veinlets or dikelets.

Certain inferences can be drawn from the foregoing observations: (1), The magma from which the silicate minerals formed was low in silica; there was an excess of magnesia and alumina that crystallized as spinel. (2), The crystallization of magnetite and ilmenite followed the formation of the silicate minerals; this is indicated both by the interstitial position of iron oxide grains and by the veinlets composed chiefly of iron oxide minerals. (3), The spinel inclusions indicate that the interstitial magnetite and the magnetite in veinlets formed under the same physical and chemical conditions.[1]

Both facts and inferences can be explained if one adopts the assumption of Jennings that the pyroxenite-magnetite masses formed from an ultramafic magma. Crystallization of the magma would be as follows: (1), Crystallization of magnesian silicates, in accord with the general rule that the saturation point of magnesium compounds is reached before that of iron compounds. (2), As crystallization proceeded, and the saturation point of iron was reached, magnetite would form. At the same time the silicate minerals would become iron-magnesian, both by precipitation of new material and by reaction of the magnesian cores with iron-rich magma. (3), With the exhaustion of the available silica, the last material to crystallize would be ilmenite, spinel, and magnetite that contained spinel in solid solution. (4), Upon cooling, the spinel in solid solution would separate from the magnetite as lines of grains along the crystal planes. This process would provide a residue composed almost entirely of magnetite and ilmenite, which by an operation akin to filter-pressing could form minor injections in the solidified parts of the ultramafic bodies. It would explain the association of magnesium-rich silicate minerals with iron oxides, because the amount of iron in the silicate grains would be controlled not by the abundance of iron, but by the scarcity of silica.

The foregoing explanation of the iron ore veinlets is essentially the same as that advanced by Osborne for certain deposits in the Adirondack and Quebec regions (1928, passim.). The deposits that Osborne studied are in anorthosite that shows many cataclastic features, and Osborne pointed out that this evidence of mechanical deformation supported the theory that the ores had been concentrated by filtration differentiation. Cataclastic features are absent in the Caribou pyroxenite, but this does not preclude the possibility that the iron ores were concentrated by filter pressing; it is quite possible that the rock was not compressed enough to cause granulation of the silicate minerals, or that a later intrusive recrystallized the augite grains.

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[1] Ramdohr (125, p. 350) found that spinel-magnetite intergrowths become homogeneous upon heating, the resolution of the spinel beginning at 800°. He concluded that they formed at the same temperature. Greig (1932, p. 31), discussing intergrowths of ilmenite and hematite, commented that in all probability inclusions of this type form at a temperature lower than that required to cause resolution.

The possibility that the pyroxenite and titaniferous magnetite formed from an ultramafic magma is opposed by the well-known conclusions of Bowen (1928), who has presented much evidence for his belief that ultramafic masses form from gabbroic magma by the accumulation of early-formed ferromagnesian minerals. Some theoretic support for the hypothesis that the Caribou pyroxenite-magnetite masses formed by the accumulation of crystals is afforded by Bastin's diagram illustrating the chemical relations of the rocks (1917, Fig. 3). On the diagram the lines of variation are fairly smooth for the monzonites and gabbros, and this indicates a gradation in composition for these rocks. For the ultramafic rocks, however, the curves do not follow systematic trends, and possibly this is a further illustration of a fact pointed out by Bowen:

> "In many igneous series all the rocks from basic to acid can be plotted on curves that require little smoothing and this fact, taken in conjunction with the evidence of the control of crystallization, points to the basic (basaltic) magma as the parental liquid. All rocks more "basic" than the parental liquid should, theoretically, tend to give points that are characterized by a scattering and therefore by departure from smooth curves because their composition must be determined by crystal accumulation" (1928, p. 124).

Except for this theoretic support, there is no positive evidence that the ultramafic masses formed by accumulation of crystals from a magma that was more felsic in composition. There seem to be adequate reasons for believing that this mode of origin does not account for certain features. If one assumes that the masses formed from a gabbroic or more felsic magma, the early crystallization of magnesian olivine and pyroxene would take place as described for an ultramafic magma, and when the saturation point for iron was reached, magnetite would form. This magnetite might contain spinel in solid solution, but it is doubtful that grains of spinel would crystallize from a magma that also contained much silica. Also, if the pyroxene crystals were in contact with a silicic magma that was saturated with respect to iron, reaction to form iron-rich minerals should have taken place. There is, furthermore, the difficulty of explaining the veinlets of magnetite. That they represent injections not only is the conclusion of the present writer, but also was recognized by Bastin:

> ". . . the differentiation was followed locally by the intrusion of the iron-rich product into the more silicate types" (1917, p. 42).

An opinion as to the possibility of an ultramafic magma that differs from Bowen's is expressed by Osborne, whose discussion includes not only several deposits that he examined, but also an extensive review of publications dealing with similar ores:

> "Sufficient evidence has been presented to show that the iron ores and pyroxene may crystallize from a magma at a sufficiently late stage to yield restmagma containing a concentration of iron and pyroxene" (1928, p. 749).

The weight of the evidence, therefore, favors the conclusion that the pyroxenite and magnetite masses formed from an ultramafic magma.

Alternative hypotheses that were considered and discarded should be pointed out here: One was the possibility that the pyroxenite masses formed by contact metamorphism of pre-Cambrian calcareous rocks. This interpretation was adopted by Lovering and Goddard:

> "Some facies of the olivine-biotite-amphibolite-magnetite rocks of the stock so closely resemble the metamorphic 'lime-silicate' member of the surrounding Idaho Springs formation, that the writers feel confident the two are identical. . . . It is believed that xenoliths of the lime-silicate rock have reacted with the gabbro and monzonite magmas, creating the peculiar ultra mafic rocks that have generally been regarded as differentiates" (1938, p. 59).

If of this origin, one would expect the ultramafic masses to contain, in a few places at least, such typical calcium silicate minerals as garnet and epidote in addition to pyroxene, and perhaps some calcite and quartz, also. In the larger masses one would expect to see interbedded layers of rocks common in the Idaho Springs formation—quartz-biotite schist, or sillimanitic schist, or granitic injection gneiss. None of these expectable features was seen during the present study, and none was reported by Lovering and Goddard or by previous workers, so the hypothesis lacks support. The lack of essential field evidence also prevents acceptance of a theoretically sound suggestion that Lovering and Goddard made concerning the origin of the titaniferous magnetite:

> "The introduction of dolomitic fragments should cause reactions yielding olivine and basic pyroxene, probably accompanied by the separation of titaniferous magnetite" (1938, p. 61).

This suggestion, furthermore, does not give adequate consideration to the fact the xenoliths available from the Idaho Springs formation would be biotite-garnet, or amphibole, or pyroxene rocks, not dolomite. The reaction of such material with gabbro or monzonite would be complex, and the products of reaction difficult to predict.

A second tentative hypothesis would explain the titaniferous magnetite as material introduced into older pyroxenite by some process of metallization. In accordance with this hypothesis, the interstitial position of magnetite and ilmenite in the pyroxenite would be considered a logical result of metasomatic replacement along pyroxene grain boundaries, and the networks in which the iron oxides are concentrated would be classed as veins, rather than dikes. Should these interpretations of textural features be correct, they would strongly support the hypothesis of metallization; the same features seem to be explained in a different way by the alternative theory that the titaniferous magnetite was the last residue of an ultramafic magma. Positive support for the theory of metasomatic deposition would be the presence of typical iron-rich silicates or minerals notably rich in volatile constituents. Only the hornblende and biotite are of the required character, but apparently their origin is not linked with that of the titaniferous magnetite.

In the present report, as well as in that of Jennings, the origin of the ultramafic masses and associated titaniferous magnetite are considered to be a problem separate from the rest of the stock. Bastin, on the other hand, considered the entire stock, including the titaniferous magnetite, to have formed by differentiation from a single magma:

> "The monzonite stocks of Caribou and of Bald Mountain, northwest of Caribou, are unique for the region covered by this report in showing in a marked degree the effects of magmatic differentiation—that is, the separation of the molten magma into portions that were chemically different and that on cooling formed rocks of different types. The extreme product of this process of differentiation has been the formation of several bodies of titaniferous iron ore . . . " (1917, p. 42).

Bastin based his theory of magmatic differentiation partly on field evidence:

> "In the Caribou ores evidences of origin by magmatic differentiation are found: (1) in the general form and situation of the bodies of gabbro and iron ore which are irregular bodies lying

wholly within the monzonite stocks; (2) in observed transitions from iron ore to gabbro and from gabbro to monzonite, an evidence whose validity is not annulled by the presence in a few places of sharp contacts between these different rock types" (1917, p. 48).

The present study confirms Bastin's first item of evidence except in two respects: First, there are masses of gabbro and ultramafic rock that lie between schist and monzonite rather than wholly within monzonite. This is indicated on the geologic map of the stock (Pl. 3). In Bastin's report, also, ultramafic rock is shown in contact with schist on a sketch map of the underground workings at the Up to Date mine (1917, p. 178). Second, masses of iron ore have a definite form: They are long and relatively narrow bodies that occupy zones of fissures extending parallel to the lateral margins of the enclosing ultramafic bodies.

That the gabbroic and ultramafic masses are wholly irregular in shape is well shown on the geologic map. It is not clear, however, why this irregular form should be considered as evidence of magmatic differentiation. On the contrary, if these masses, or the stock as a whole, were regular in shape or structure, or had a systematic arrangement, such as a definite stratification or a concentric structure, there might be more reason for seeking a process that would produce the diverse rocks from a single magma. However, even such a character would not be of itself proof of magmatic differentiation. The possibility that either the individual masses of gabbro and ultramafic rocks or the stock as a whole once had some regular or systematic arrangement which is now disordered seems remote. Although the similarity of composition indicates that the ultramafic masses are parts of one body, or formed from similar material, there are no internal characteristics suggestive of a former unit of definite structure. This is also true of the gabbroic masses. Mechanical derangement of the stock is inadequate to explain the irregular distribution of the rock varieties because the faults and fractures, although abundant, show no relationship to the distribution of the ultramafic and gabbroic masses. It is believed, therefore, that the theory of magmatic differentiation in place explains neither the irregular form of the mafic bodies nor their unsystematic arrangement. On the other hand, if the diverse rocks formed by successive intrusions and metasomatic alterations, the irregular shapes and unsystematic distribution are readily explained as products of:

(1), irregular original form, (2), breaking up of older rock bodies by younger magmas, and (3), unequal metasomatic alteration. The titaniferous magnetite, which is always within pyroxenite, is of course an exception to the rule that the rocks are unsystematically distributed.

The second item given by Bastin as evidence for magmatic differentiation concerns the contacts between the rocks of the stock. In the interpretation of these contacts the present report differs greatly from that of Bastin; whereas he concluded that there was a gradation from gabbro to iron ore, the present writer considers the gradation to be only an apparent one, brought about by the mixture of gabbroic magma with fragments of older pyroxenite. At the contacts of monzonite with gabbro or monzonite with ultramafic rock no zones of this type were seen; in fact, sharp contacts between these rocks were observed, as is implied in Bastin's statement. Furthermore, examination showed that at the many places where monzonite and ultramafic rock are in contact there is no intermediate gabbro. In addition to these reasons for believing that there is no true gradation from one rock to another, certain observations that show the relative ages of the rocks are also evidence against there being gradations—namely, the apophyses of one rock cutting another and the angular fragments of one rock in another. Bastin also reported angular fragments of mafic rock in monzonite, but he believed that this did not oppose the evidence of gradation (1917, p. 42). In the present report, on the other hand, these fragments are considered to be positive evidence of relative age. The evidence of the fragments could be disregarded only if they showed contradictory relationships, but this is not the case. In every instance the fragments are more mafic than the enclosing rock, and no reversal of this was seen.

Although the theory of differentiation does not explain the presence of mixed zones at some places and sharp contacts at others, these features would be expected under the variety of conditions that would arise during the intrusion of a series of magmas that differed one from another.

In addition to the two items of field evidence in support of the differentiation theory, Bastin presented two others based on chemical analyses and microscopic study:

> "(3) . . . the consistent character of the variations in chemical composition, as shown in the diagram . . .;
>
> (4) . . . the mineralogic gradation traceable from one rock type to another . . ." (1917, p. 48).

An alternative interpretation of the diagram has already been pointed out. It should also be mentioned that the rocks analyzed came from widely separated localities in the stock. This is justified by the necessity of getting fresh material; nevertheless, the fact that the rocks analyzed do not come from one line extending from iron ore to quartz monzonite detracts greatly from the force of the argument. Moreover, the analyses serve equally well as evidence that the successive intrusions came from one chamber of magma, and the similarity of the minerals is subject to the same interpretation. Neither item of evidence, therefore, is conclusive; both might support either Bastin's explanation or the one offered in the present report.

It will be seen from the foregoing discussion that Bastin sought an interpretation of the stock that would explain all the rocks as products of one magma that differentiated in place. In accordance with this theory of origin, Bastin classed the ten varieties of rock that he described as members of a gradational series. The present study has shown that the variety of rocks is even greater than Bastin reported, although some rocks that he described were not found. The evidence presented in this report indicates that some of the rocks formed from separate intrusions of magma and others by metasomatic alteration of the primary intrusives. The stock, therefore, is a composite body made up of rocks that formed in the following order: (1), magnetite-rich pyroxenite; (2), augite gabbro; (3), augite monzonite; and (4), minor varieties—aplite, pegmatite, monzonite porphyry, and lamprophyre. The crystallization of silicate minerals from the oldest, ultramafic magma produced an iron-rich residue which was concentrated by filter-pressing to form masses of titaniferous magnetite. The stock also contains small masses of rocks formed by serpentinization, hornblendization, and probably biotitization of the primary types. These conclusions, which are based on field and petrographic evidence found in the rocks of the Caribou stock itself, are supported by additional evidence from the adjacent Tertiary intrusives. The presence of stocks and dikes of diverse composition shows that a variety of magmas invaded the pre-Cambrian rocks of the area, and the fact that the Lake Isabelle stock consists of monzonite that encloses older masses of hornblendized pyroxenite and diorite supports the theory of origin here advanced for the Caribou stock.

ACKNOWLEDGMENTS.

It is a pleasure to express appreciation of assistance received during this study. Especial thanks are due to Prof. Adolph Knopf, under whose direction the work was carried on at Yale University, and to Dean C. H. Warren and Prof. A. M. Bateman for helpful criticism. Dr. T. S. Lovering, of the U. S. Geological Survey, suggested the study and made valuable contribution during the field work. Dr. E. M. Van Tuyl, of the Colorado School of Mines, kindly provided plane table equipment. During mapping of the northern part of the area, Mr. E. Waldstrom, of the University of Colorado, was generous in sharing his knowledge of the region. In every part of the work the writer has enjoyed the continuous help of Jean Stewart Smith.

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Ramdohr, P.: Beobachtungen an Magnetit, Ilmenit, Eisenglanz usw., Festschrift zur Jahrfeier der Bergakademie, Clausthal, 1925.

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THE BEARING OF THE VALENTINE AREA IN CONTINENTAL MIOCENE-PLIOCENE CORRELATION.

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ABSTRACT.

The real significance of the faunas of the Valentine area of Nebraska has largely been overlooked because of the controversy over names. Because of this the true relationships of the faunas and their significance in world correlation are pointed out. Evidence is presented which supports the retention of the names Niobrara River, Burge and Valentine. *Protohippus* is shown to be a synonym of *Merychippus*.

INTRODUCTION.

The fossil mammals of the Valentine area of Nebraska have long been used as a basis of correlation for deposits of other parts of America and the Old World containing late Miocene and early Pliocene mammals. The deposits and faunas of this area have received many names such as Loup Fork, Loup River, Niobrara River, Fort Niobrara, Mastodon beds, Nebraska, *Cosoryx* beds, and Valentine. Since 1917, when Barbour and Cook[1] used the term Valentine, the other names have gradually lost favor and Valentine has come into almost universal usage. All of the names, including Valentine, which were used to indicate a unit fauna, were applied to the deposits in general. Field work in 1933 and 1934 by R. A. Stirton and P. O. McGrew proved the presence of three distinct, successive faunas in this region. Therefore, in order to facilitate ready and definite reference to these beds and their faunas, a separate name for each was proposed.[2] The names chosen were: Niobrara River, for the lowest fauna, believed to be late Miocene in age; Burge, for the intermediate fauna which was regarded as basal Pliocene; and Valentine, the upper fauna which was thought to be transitional between early and middle Pliocene.

This arrangement of names has not been accepted by most other writers interested in the problem. The term Valentine appears in several papers with the statement that it is being used in place of Niobrara River, the lower fauna. In these papers, however, it is regarded as Lower Pliocene.

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[1] Barbour, E. H., and Cook, Harold J.: "Skull of *Aelurodon platyrhinus*, sp. nov" Neb. Geol. Surv. Vol. VII, p. 173 and 180, 1917.

[2] Stirton, R. A., and McGrew, Paul O.: "A Preliminary notice on the Miocene and Pliocene Mammalian Faunas Near Valentine, Nebraska," This Journal, Vol. 29, 1935.

Colbert[3] wrote: "The name Valentine is well established in the literature to indicate the formation and the time transitional between Miocene and Pliocene, and the abandonment of this usage of the term will lead to some confusion. Lacking more detailed and conclusive evidence on the question of the proposed division, the name Valentine, indicative of the transition from the Miocene to the Pliocene, is retained in the foregoing pages in its original meaning."

Johnson[4] published a paper entitled "The status of the name 'Valentine' in Tertiary geology and paleontology," in which he complicated matters further by limiting the term Valentine to the lower fauna (the Niobrara River of Stirton and McGrew) and by suggesting a new name "Cap Rock beds" for the upper mammal bearing horizon. He did, however, retain the name Burge for the intermediate fauna.

Wilson[5] stated "Since the present author is in no position to judge the merits of either name, and since Valentine has been adopted by most paleontologists including those of the Nebraska Geological Survey and the Nebraska State Museum, this term will be used in the present paper."

Teilhard and Stirton,[6] and Stirton[7] have employed the divisions essentially as proposed by Stirton and McGrew.

It is obvious that some agreement must be reached in this question of names. In view of the non-acceptance of the proposed divisions, such as the use of different names to designate one fauna and the use of the same name for different faunas, it seems imperative that additional information bearing on the problem be presented.

It is hoped that this discussion will result in: 1. a uniform usage of the terms Niobrara River, Burge, and Valentine; 2. a unified opinion concerning the stratigraphic and phyletic relationships of the faunas of the Valentine area, and 3. a clearer understanding of the Miocene-Pliocene boundary. In addition a solution to this problem may help to make possible more accurate correlation of the various late Miocene-early Pliocene faunas of America, as well as those of the Old World.

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[3] Colbert, E. H.: "Distributional and Phylogenetic Studies on Indian Fossil Mammals," Am. Mus. Novitates, No. 797, p. 14, 1935.

[4] Johnson, F. W.: "The Status of the name 'Valentine' in Tertiary Geology and Paleontology," This Journal, Vol. 31, p. 467, No. 186, 1936.

[5] Wilson, Robert W.: "Pliocene Rodents of Western North America," Carnegie Inst. Wash., Publ. 487, p. 32, 1937.

[6] Teilhard de Chardin, P., and Stirton, R. A.: "A Correlation of some Miocene and Pliocene Mammalian Assemblages in North America and Asia with a Discussion of the Mio-Pliocene Boundary," Univ. Calif. Publ. Bull. Dept. Geol. Sci., Vol. XXIII, 1935.

[7] Stirton, R. A.: "Succession of North American Continental Pliocene Mammalian Faunas," This Journal, Vol. 29, 1936.

THE HORSES OF THE VALENTINE AREA AND THEIR SIGNIFICANCE IN CORRELATION.

The horses are widely recognized as providing the best criteria for correlation between widely separated Tertiary mammal bearing deposits and hence, as the best means for the determination of the age of deposits containing a horse fauna.[8] Matthew[9] pointed out the following reasons for regarding the Equidae as the most reliable basis for correlation:

1. They are abundant, especially in later tertiary, but are found in every post Clark Fork fauna of importance.
2. There is comparative unity in the family. In the main it is a direct, continuous, progressive series.
3. The molars progress in complexity to a highly characteristic pattern so that single teeth can be recognized and placed exactly. Corresponding specialization in the feet makes the foot bones diagnostic also.
4. The wide geographic dispersal of the Equidae makes them of great value also in intercontinental correlations.

Now that the phylogeny of different mammalian families, especially the Camelidae, Oreodontidae, Canidae, and Rhinocerotidae is fairly well known it is possible to use these forms with a considerable degree of confidence for correlation. It is certainly true, however, that evidence afforded by fossil horses remains the most dependable medium for correlation of the Tertiary continental deposits and probably will continue to outweigh that of any other mammalian group.

The beginning of Pliocene times in North America is regarded as that time when the horses lost their merychippine characters and became well defined species of *Pliohippus* and *Neohipparion*. The transition of the horses will probably continue to mark the Miocene-Pliocene boundary. As evidence that this time represents the transition between Miocene and Pliocene Matthew cited the migration of *Hipparion* to the Old World. He regarded the migration as being due to diastrophic unrest which affected environmental conditions. This orogeny, he believed, coincided closely with the time represented by the unconformity between the Miocene and Pliocene marine series of the type locality.

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[8] Simpson, G. G.: "Glossary and Correlation Charts of North American Tertiary Mammal Bearing Formations," Bull. Am. Mus. Nat. Hist., Vol. LXVII, 1933.

[9] Matthew, W. D.: "Correlation of the Tertiary Formations of the Great Plains," Bull. G. S. A., Vol. XXXV, p. 745, 1924.

Horses are the most abundant of the many mammals that occur in the faunas of the Valentine area and offer sufficient evidence to determine their age accurately.

The faunal list (see p. 202) shows that the following species of equids are found in the lower or Niobrara River fauna: *"Protohippus" perditus, Merychippus republicanus, Merychippus insignis, "Protohippus" placidus* and *Hypohippus* cf. *affinis.* Although *Merychippus republicanus* and *Merychippus insignis* are recognized as typical late Miocene species *"Protohippus"* is thought by many to represent a typical lower Pliocene form.[10] As shown below, however, *"Protohippus"* is synonymous with *Merychippus.*

The status of "Protohippus." A recent study of the genus *"Protohippus"* indicates that its relationships have been generally misunderstood and it is necessary to correct this misunderstanding before we can use this form as evidence for correlation.

The genotype of *"Protohippus"* is *"P." perditus* Leidy, and the holotype of this species was collected by Hayden from the "Niobrara River" near Fort Niobrara in 1857. Subsequent collecting has proved beyond a doubt that Leidy's specimen came from the lower exposures of the Valentine area which yielded the Niobrara River fauna.

The present consensus among paleontologists is that *"Protohippus"* is a small form with the protocones connected with the protolophs on the upper cheek teeth. This conception is the result of the reference by Leidy of *"Protohippus" placidus* and certain species of *Nannippus* to *"Protohippus."* When the holotype of *"P." perditus* is compared, however, it is obvious that no relationship exists between these small horses and the genotype of *"Protohippus."*

The characters of *"Protohippus" perditus* are such that there can be little doubt that this species is ancestral to the Pliocene genus *Pliohippus,* just as the contemporary *Merychippus republicanus* is ancestral to the Pliocene species of *Neohipparion.* The teeth of *"Protohippus" perditus* differ from those of typical *Pliohippus* only in having more primitive characters, being smaller, shorter crowned, and having a slightly more primitive pattern. These characters are those of *Merychippus.* thus leaving us no alternative but to relegate *"Protohippus"* to the synonomy of this genus.

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[10] Simpson, G. G.: "Glossary and Correlation Charts of North American Tertiary Mammal Bearing Formations," Bull. Am. Mus. Nat. Hist., Vol. LXVII, p. 81, 1933.

Every species which has been referred to *"Protohippus"* (with the exception of *"Protohippus" placidus*) fits into another well known genus.

"P." parvulus is an advanced species of *Merychippus.*

"P." placidus does not fit into any known genus but certainly is not related to *"Protohippus" perditus.*

"P." niobrarensis is a species of *Nannippus.*

"P." simus is a good species of *Pliohippus.*

"P." pachyops is a species of *Pliohippus.*

"P." tehonense is either an advanced *Merychippus* or a primitive *Pliohippus.*

"P." retrusus is a species of *Nannippus.*

"P." profectus is best referred to *Pliohippus.*

An earlier species of *Merychippus, "Protohippus" perditus* and *Pliohippus* are successive members of one line of descent. All species of this line which are more primitive than *"Protohippus" perditus* are species of *Merychippus* and all which are more advanced are species of *Pliohippus.* If the name *"Protohippus"* is retained it will have to be limited to one species, the genotype, and will have to be limited to an extremely short geologic span, Niobrara River and equivalents.

"Protohippus" perditus is found in the same quarries with *Merychippus republicanus* and *Merychippus insignis* and its characters are no more advanced than are those of these contemporary species. The fact that *Merychippus insignis* is the type species of *Merychippus* strongly reinforces the relegation of *"Protohippus"* to this genus.

Thus, the horses of the Niobrara River fauna clearly prove that the age of this lower horizon is upper Miocene.

The horses of the Burge and Valentine faunas. The Burge horses are referable to four species, *Pliohippus supremus, Neohipparion* cf. *coloradense, Nannippus retrusus,* and *Hypohippus affinis.* Each of these species appears to have been derived directly from the more primitive species found in the underlying beds. *Pliohippus supremus* was derived from *Merychippus* (= *"Protohippus"*) *perditus, Neohipparion* cf. *coloradense* from *Merychippus republicanus,* and *Nannippus retrusus* from *Merychippus insignis.* These species are the most primitive forms of their respective genera that at present are known. Therefore the Burge fauna is considered lowermost Pliocene.

The Valentine horses are similar to those of the Burge, but appear to be somewhat more advanced. *Nannippus gratum* of the Valentine is more progressive than *N. retrusus* and the Valentine species of *Pliohippus* and *Neohipparion* are rather more advanced than are those of the Burge. The *Procamelus* of the Valentine is close to *Pliauchenia* and a primitive *Megatylopus* appears here for the first time. It seems then that the Valentine fauna is somewhat later than the Burge, but not sufficiently so to be regarded as middle Pliocene. The age assigned to the Valentine, on the basis of its fauna is upper, lower Pliocene.

FAUNAS OF THE VALENTINE AREA.

Niobrara River	Burge	Valentine
Metechinus sp.		
Mookomys sp.		
Mylagaulus sp.	*Mylagaulus* sp.	
Monosaulax	*Eucastor* sp.	Castoridae indet.
Cynodesmus sp.	*Cynodesmus euthos*	*Pliocyon* sp.
Vulpes vafer	*Vulpes vafer*	*Leptarctus* sp.
	Aelurodon sp.	
Bassariscus antiquus		
Pseudaelurus sp.		
Mustelidae indet.		
Proboscidea indet.	Mastodontinae indet.	
		Teleoceras sp.
Hypohippus sp.	*Hypohippus affinis*	*Hypohippus* sp.
Merychippus insignis	*Nannippus retrusus*	*Nannippus gratum*
Merychippus perditus	*Pliohippus supremus*	*Pliohippus* sp.
Merychippus republicanus	*Neohipparion coloradense*	*Neohipparion* sp.
Prosthennops xyphodonticus	*Prosthennops* sp.	
Procamelus sp.	*Procamelus* sp.	*Procamelus* sp.
	Alticamelus sp.	*Alticamelus* sp.
Merycodus sp.	*Merycodus* sp.	*Megatylopus* sp.
Blastomeryx sp.		

USAGE OF THE TERM VALENTINE.

The Ricardo of California contains a *Pliohippus-Neohipparion* fauna. Matthew,[11] Simpson,[12] and most others have regarded the Ricardo as the approximate equivalent of the

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[11] Matthew, W. D.: Op. cit., facing p. 746.

[12] Simpson, G. G.: "Glossary and Correlation Charts of North American Tertiary Mammal Bearing Formations." Bull. Am. Mus. Nat. Hist. Vol. LXVII p. 88, 1933.

Valentine. The Valentine, on the other hand, has never been correlated with the Barstow, which is recognized as uppermost Miocene. It is obvious, therefore, that when these writers used the term "Valentine" they were not thinking of the primitive *Merychippus* assemblage of the Niobrara River fauna. Rather they were using the *Pliohippus-Neohipparion* fauna of the upper levels as the basis for correlation. When studied as a unit the Niobrara River fauna is seen to have close relationships with that of the Barstow, whereas the Ricardo is distinctly later. Both Matthew[13] and Colbert[14] mentioned *Nannippus* (= *"Hipparion"*) *gratum* as being from the Valentine, thus proving further that it was the later fauna that was thought of as the Valentine fauna.

The almost universal misunderstanding of the faunal assemblages of the Valentine area was further illustrated by Colbert[15] when he said, "The upper Miocene species such as *Merychippus republicanus*. . . . ," followed by (p. 13) "The Niobrara River fauna. . . . is equivalent to the Valentine fauna contained in the Valentine formation, as used by Matthew, Simpson, and others." In these statements he voiced the common opinion that the advanced species of *Merychippus* were of late Miocene age, but called the fauna in which they occur Valentine. Furthermore he regarded the Valentine as Pliocene.

It seems that the misconceptions which have arisen concerning these faunas are the result of the primitive collecting methods used by the early paleontologists, who failed to segregate their assemblages. In addition, an important factor is the conservative tendencies of many modern paleontologists who dislike abandoning established usages even though they are incomplete, misleading, or erroneous.

Because most early collecting in the Valentine area was carried on in the vicinity of Fort Niobrara, it is doubtful that the Burge fauna was encountered. It is likely that the fossil mammals which led to the assumption that the beds as a whole were Pliocene are those from the upper levels along the Niobrara River near Fort Niobrara. It was with this in mind that the name Valentine was limited by Stirton and McGrew to the upper beds. If the name is retained for these beds there should be no confusion as it will leave the name in its original standing; a name to designate a lower Pliocene fauna of the Valentine area.

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[13] Matthew, W. D.: "Critical Observations Upon Siwalik Mammals," Bull. Am. Mus. Nat. Hist., Vol. LVI, p. 45. 1929.

[14] Colbert, E. H.: "Distributional and Phylogenetic Studies on Indian Fossil Mammals," Am. Mus. Novitates, No. 797, p. 10, 1935.

[15] Ibid, p. 5.

It was necessary to apply a name to the upper Miocene fauna of the same area to distinguish it from the Pliocene Valentine. The name Niobrara River was chosen and has been used in several papers to designate the lower fauna. It should continue to be used in that sense in the future. If the lower fauna were called "Valentine" as has been suggested, it would detract considerably from all correlations which have been made employing the name Valentine, notably those of Matthew and Simpson.

Johnson[16] insisted that Niobrara River could not be applied to the lower fauna because the name Valentine had priority for this horizon.[17] But Barbour and Cook's name was proposed for reference to the whole series of beds and not to the one horizon or fauna. This is not only proved by the faunal list published in the 1917 paper but also verified by oral communication with Harold J. Cook. Johnson's substitution of Valentine for Niobrara River in the sense used by Stirton and McGrew is therefore unjustified. His term Cap Rock for the uppermost beds is an unnecessary synonym.

APPLICATION TO OLD WORLD CORRELATION.

All dependable evidence points to the fact that *Hipparion* of the Old World is of North American origin. No pre-Pliocene form has ever been found in the Old World which could possibly have given rise to the *Hipparion* which occurs in the Sarmation of Europe and the Chinji of India. On the other hand, in North America *Hipparion mohavense* of the Ricardo has characters which make it a perfect structural ancestor of the Old World *Hipparion*. On this evidence it is safe to assume that *Hipparion* reached Eurasia by migration from North America. If this is true it is also immediately apparent that the presence of *Hipparion* in a deposit of the Old World proves that such a deposit was laid down subsequent to the first appearance of *Hipparion* in America. The earliest Hipparions (*H. mohavense* is one of the earliest) of North America are found in deposits of earliest Pliocene age. (Ricardo, Burge, Esmeralda, etc.) The first appearance of

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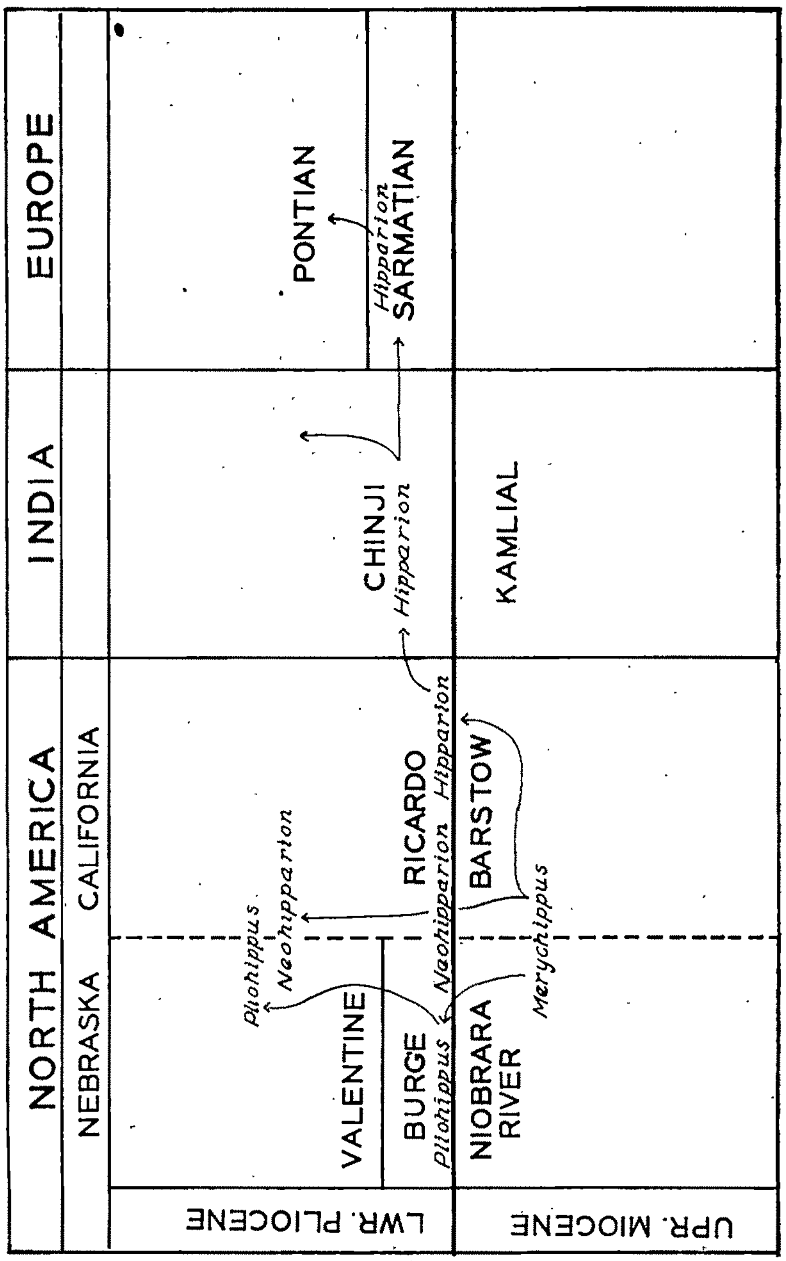
[16] Johnson, W. F.: "The Status of the name "Valentine" in Tertiary Geology and Paleontology," This Journal, Vol. 31, pp. 469 and 471, 1936.

[17] Barbour, E. H., and Cook, Harold J.: "Skull of *Aelurodon platyrhinus*, sp. nov." Neb. Geol. Surv., Vol. VII, 1917.



Correlation of the faunas of the Valentine area with those of California, India and Europe (Modified from Colbert).

Hipparion in Europe is in the Sarmatian (Sebastopol) and in India the Chinji. The only conclusion is that the Sarmatian and Chinji are at least as young as early Pliocene.

Lewis,[18] in "A new Siwalik correlation," expressed the view that the Chinji formation is of late Miocene age. He followed a principle of correlation similar to that of Matthew and Colbert but based his conclusions upon the apparently erroneous assumption that *Hipparion* appeared in the Miocene of America. He based this assumption that *Hipparion* appeared in the Miocene on the reported occurrences of this genus in the Puente and Mint Canyon formations of California.[19] Neither of these appears to be Miocene. In fact, as shown below, there is every indication that the beds are Pliocene.

The first supposed Miocene occurrence of *Hipparion* was that of a tooth of *Hipparion mohavense* in the Puente formation of California, reported by Stock.[20] Regarding this formation Stock said, "Prior to the discovery of the *Hipparion* tooth the Puente formation in the area mapped by English yielded no diagnostic fossils on which an age determination could be based. The age of the formation was suggested by the fact that the Puente lies between the Middle Miocene Topanga and the [Middle] Pliocene Fernando. The occurrence of *Hipparion mohavense* in beds of the upper portion of the Puente furnishes evidence that the deposits are either lower Pliocene or Uppermost Miocene in age. If we accept the view that the genus *Hipparion* appeared in North America in the late Miocene, then the presence of *H. mohavense* in the Puente would lend further support to this view, since the Puente has been correlated with upper Miocene formations rather than with lower Pliocene deposits on the basis of independent stratigraphic evidence."

H. mohavense is characteristic of the Ricardo Pliocene and it would seem that its occurrence in the Puente would establish an early Pliocene age for the latter formation. This is especially true since on pure stratigraphic evidence the Puente could be of any age between middle Miocene and middle Pliocene.

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[18] Lewis, G. Edward: "A New Siwalik Correlation," This Journal, Vol. 33, 1937.

[19] Maxon, John H.: "A Tertiary Mammalian Fauna from the Mint Canyon formation of Southern California," Carnegie Inst. Wash., Publ. 404, 1930.
Stock, Chester: "A Tooth of *Hipparion Mohavense* from the Puente Formation, California," Carnegie Inst. Wash., Publ. 393, 1928.

[20] Stock, Chester: Ibid.

Lewis's other reported Miocene occurrence of *Hipparion* was that in the Mint Canyon fauna of California.[21] Previous to the appearance of Lewis's paper, however, Stirton had clearly shown that the fauna from Mint Canyon is typically lower Pliocene and that it bears relations with the Ricardo and Esmeralda and not with the Barstow as Maxon thought. Although of the utmost significance in this problem, Stirton's paper was not cited by Lewis.

Thus, because true *Hipparion* has never been found in deposits which can be demonstrated to be of Miocene age, the correlation by Lewis must be rejected. Furthermore, unless some unexpected evidence turns up, the appearance of *Hipparion, Neohipparion,* and *Pliohippus* should continue to mark the beginning of Pliocene in North America.

[21] Maxon, John H.: Op. cit.

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COMMENTARY ON McGREW AND MEADE'S PAPER.

G. EDWARD LEWIS.

Stirton and McGrew[1] and McGrew[2] are to be commended on their work in restudying the "Valentine" equids, and on discriminating between the faunae of the Valentine area. The writer is in entire agreement with this separation of faunae, but feels that the highly controversial problem of nomenclature of the faunal units is best left to students better qualified than himself. It may be remarked that geographic names as used for mappable formations should not be given to faunal zones. This subject was adequately discussed at the 1935 meetings of the Vertebrate Section of the Paleontological Society. *Seriatim*, there are several points in the foregoing paper with which the writer is concerned:

I. "*Hipparion mohavense* of the Ricardo has characters which make it a perfect structural ancestor for the Old World *Hipparion* . . . *Hipparion* reached Eurasia by migration from North America"[2] (See p. 204).

McGrew and Meade are in entire agreement with the writer's previously published interpretation[3] (pp. 195-197) and completely at odds with Stirton, who does not feel that *Hipparion* was derived from any North American representative of this genus, suggesting that just the opposite took place: ". . . the Old World Hipparions are probably descendants of an unknown Asiatic *Merychippus* or a *Merychippus* in this country [U. S.] older than the Niobrara River fauna . . . Perhaps the appearance of *H. mohavense* in the Pacific Coast faunas is the result of an influx of North Asiatic or Alaskan animals"[4] (pp. 282-283).

II. "The earliest *Hipparions* . . . of North America are found in deposits of earliest Pliocene age . . . The first appearance of *Hipparion* in Europe is in the Sarmatian (Sebastopol) and in India the Chinji. The only conclusion is that the Sarmatian and Chinji are at least as young as early Pliocene"[2] (See p. 204 and 206).

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[1] Stirton, R. A., and McGrew, P. O.: This Journal, 29, 1935.

[2] McGrew, P. O., and Meade, G. E.: This Journal, 35, 1938.

[3] Lewis, G. E.: This Journal, 33, 1937.

[4] Stirton, R. A.; in Teilhard de Chardin, P.; and Stirton, R. A.: Univ. Cal. Bull. Dept. Geol. Sci., 23, 8, 1934.

It is impossible to be dogmatic about this type of problem. There is certainly more than the one conclusion reached above. Until recently, *Hipparion* was considered to appear in North America at the beginning of Pliocene time, this having been a working hypothesis accepted by Osborn, Merriam, and Matthew twenty years ago[5] (p. 9) when the relations to the Pacific Coast marine section were imperfectly known. Borissiak[6] (p. 43) makes it quite clear that the Sebastopol fauna is of middle Sarmatian age, occurring in deposits intercalated in the Standard marine section of the upper Miocene. Gripp has reported the discovery of *Hipparion* associated with a late Miocene marine fauna in the Glimmerton of the island of Sylt in the North Sea.[7] Stirton recognized the validity of this evidence[4] subsequent to his paper on the Mint Canyon,[8] and, not admitting the pre-Pliocene occurrence of this genus, was forced to the conclusion previously quoted[4] (pp. 282-283). Maxson[9] and Stock[10] have published on the discovery of *Hipparion* in deposits presumably of late Miocene age. Denials of the correctness of these reports of Miocene *Hipparion* have been made, but to date there has been no evidence acceptable to the writer to bolster up these denials. Until such evidence is presented, it seems best to regard the occurrences as Miocene.

III. "Lewis, in 'A New Siwalik Correlation,' expressed the view that the Chinji formation is of late Miocene age. He . . . based his conclusions upon the apparently erroneous assumption that *Hipparion* appeared in the Miocene of America . . . on the reported occurrence of this genus in the Puente and Mint Canyon formations of California. Neither of these appears to be Miocene. In fact, as shown below, there is every indication that the beds are Pliocene . . . Stirton had clearly shown that the fauna from the Mint Canyon is typically lower Pliocene . . . Although of the utmost significance in this problem, Stirton's paper was not cited by Lewis"[2] (See pp. 206 and 207).

McGrew presents no evidence to prove this assertion. Since the writer has been unable to make a careful field study of the Puente and Mint Canyon localities, he is open-minded. An examination of published conclusions and evidence based on careful field work seems to warrant adherence to his previous interpretation,[8] in which Stirton's paper[8] was not cited because it was not regarded as having disproved Maxson's age determination[9] (p. 85). Stirton's correlation depended solely on his identification of the specimens described by Maxson. The two identifications have little in common. A marine formation overlies the Mint Canyon formation with angular discordance, and, while there is no infallible proof, all available evidence indicates that it is equivalent to part of the Modelo formation of Miocene age. Maxson believes the fauna of the underlying Mint Canyon formation to be intermediate between that of the Barstow and that of the Ricardo[9] (pp. 80, 81, 83). Stirton says: "The most valuable material for correlation purposes . . . is the protohippine horse teeth," the material comprising five defective cheek teeth (only two lower premolars being associated), all "heavily worn and difficult to identify"[8] (pp. 573, 576). Considering the above facts, and bearing in mind the failure of Stirton and McGrew to present evidence for definitely referring the overlying marine beds to a post-Modelo age, the writer fails to see any cogent reason for considering the Mint Canyon fauna to be younger than late Miocene. The same conclusion applies to the Puente, probably an upper Modelo equivalent. McGrew has not mentioned applicable evidence from the Puente formation outside the area mapped by English, but does quote from Stock[10] (p. 53) as follows: ". . . the Puente has been correlated with upper Miocene formations rather than with lower Pliocene deposits on the basis of independent stratigraphic evidence." He overlooks the major uncertainty, which is not the age of the Puente, but whether or not this *Hipparion* occurs in the Puente or the Fernando. Stock presumes that it does come from the Puente[10] (p. 51).

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[5] Osborn, H. F.: Mem. Amer. Mus. Nat. Hist., N. S., 2, 1, 1918.
[6] Borissiak, A.: Mém. Com. Géol. St. Pét., N. S., 137, 1915.
[7] Gripp, K.: Zeitschr. deutsch. geol. Gesellsch., 74, 1922.
[8] Stirton, R. A.: This Journal, 26, 1933.
[9] Maxson, J. H.: Carn. Inst. Wash. Publ. 404, 7, 1930.
[10] Stock, C.: Carn. Inst. Wash. Publ. 393, 6, 1928.

IV. "Thus, because true *Hipparion* has never been found in deposits which can be demonstrated to be of Miocene age, the correlation by Lewis must be rejected"[2] (See p. 207).

This sanguine view cannot be accepted by the writer. *Hipparion* Christol was established on material from Europe. It follows that the Sarmatian and Glimmerton occurrences represent "true *Hipparion*." Competent authorities advocate its appearance in the late Miocene of the New World. It seems more prudent not to impugn their careful field work until thorough field studies of palaeontology, stratigraphy, and structure are made in conjunction with accurate mapping. Laboratory and library studies are not enough. Until we have positive evidence based on such thoroughgoing work, serious doubts cannot be cast on the late Miocene appearance of *Hipparion*, and the writer's correlation is reasonable. "The conservative tendencies of many modern paleontologists who dislike abandoning established usages" do not smack of Bourbonism as long as they are inspired by an acceptance of only well-documented conclusions.

SUMMARY.

Careful field work by competent authorities has produced evidence indicating that:

1. *Hipparion* first appears in the New World in the Mint Canyon formation. This formation is overlain unconformably by the marine Modelo formation of late Miocene age.
2. *Hipparion* occurs in the marine Puente formation of late Miocene age.
3. *Hipparion* first appears in the Old World in the marine Glimmerton and brackish-water Sarmatian, both of late Miocene age.

McGrew and Stirton must refute these three points with factual evidence to disprove the writer's correlation.

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REMARKS ON THE USE OF THE NAME "VALENTINE."

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In any discussion of the Valentine problem, which within the past few years has indeed become very complex, certain fundamental facts as to the nomenclature, stratigraphic extent and correlation of the upper Tertiary sediments of northern Nebraska must be kept in mind.

In the first place, it must be remembered that the name "Valentine" was given by Barbour and Cook in 1917, to designate a series of sediments in north central Nebraska, regarded by the original authors of the name as representing a unit series containing a unit fauna. Barbour and Cook considered the Valentine beds as representing an earlier phase of deposition than the lower Pliocene Snake Creek beds.

Subsequent to the first publication of the name "Valentine," this term (particularly through the publications of Osborn, Matthew, Simpson and others) gained wide favor among American vertebrate palaeontologists as a designation for the basal Pliocene, or transitional Miocene-Pliocene phase of the high plains of North America. Consequently it came to be applied as a time term, as well as a formation name, and in this sense became well established in the literature of vertebrate palaeontology.

A threefold division of the Valentine beds was first recognized by Cook and Cook in 1933, on the basis of field work by Stirton and McGrew. In the publication by Cook and Cook the name "Valentine" was restricted to an upper level of the series, a lower level was tentatively designated as the "Fort Niobrara," while an intermediate level was mentioned but not named. In 1934 Stirton (in Teilhard and Stirton) designated the upper and lower horizons as "Valentine" and "Niobrara River" respectively, and at the same time he listed the name "Burge" without defining it. Finally, in 1935, Stirton and McGrew named and defined the Niobrara River, Burge and Valentine levels and faunas, for the lower, middle and upper divisions respectively of the original Valentine beds. The term "Niobrara River" was applied to an assemblage of upper Miocene age, the name "Burge" was given to a lower Pliocene fauna, while the term "Valentine" was restricted to a fauna transitional between the lower and middle Pliocene.

There is no question here as to the actuality of Stirton's and McGrew's recognition of restricted faunal zones or phases within the Valentine beds; it is the choice of names for these three horizons that is regarded as unfortunate by many workers in vertebrate palaeontology. Whatever may be the reasons for restricting the term "Valentine" to the topmost levels of the series in question, the fact remains that this procedure has taken from the name its original connotation of a basal Pliocene (or according to some authors, a transitional Miocene-Pliocene) phase. It seems to the present writer that if the term "Valentine" must be restricted, its usage by many authors over a considerable period of time would almost of necessity have required its limitation to the lower levels of the series, that are approximately equivalent either to the basal Pliocene zone or to the Miocene-Pliocene transition.

Johnson, in 1936, recognized this and suggested that the name "Valentine" might be more properly applied to the lowest horizon as defined by Stirton and McGrew, than to the highest one. It seems to me that Johnson, instead of "complicating" the issue, as stated by McGrew, actually attempted to simplify it by returning the name "Valentine" to a position more nearly in accord with its original definition, as a phase lower than the Upper Snake Creek, and with its subsequent usage. (Incidentally, Johnson brought out the fact that Leidy did *not* use the name "Niobrara River" in a formational sense, but rather as a locality name, and therefore this name, as based on its original usage, has no standing as a stratigraphic unit. Stirton's argument that the term has been widely used in the literature is, for the most part, invalid. Of the numerous authors using this term, only Osborn employed it in a stratigraphic sense.)

It must be remembered that practically all authors previous to Stirton and McGrew used the name "Valentine" to denote those basal Pliocene, or transitional Miocene-Pliocene beds in which the genus *Hipparion* (in the broad sense of the term) first appears. This usage gained wide acceptance even though these authors recognized the fact that the Valentine beds probably contained more than just a basal Pliocene *Hipparion* fauna. Therefore, although Johnson's suggestion that the name "Valentine" be applied to the lowest, or upper Miocene level of the original Valentine beds approximately represents the original and well established usage of the term, it seems evident that still another procedure would have been to restrict the term to the Burge level, which is of basal Pliocene age, and in which *Hipparion* (*Nannippus*) first makes its appearance. The restriction of the name "Valentine" to the uppermost level of the original Valentine beds is not in any sense the correction of a misuse of the name, but rather the needless change of a well-established usage.

It seems to the present writer that Stirton and McGrew might have avoided a great deal of confusion by:

a. Applying the term "Valentine" to the lowest horizon, which they have called "Niobrara River." This was the course suggested by Johnson, in 1936.

b. Using the term "Valentine" for the middle horizon, which they have named "Burge," and which, according to their evidence is truly of lower Pliocene age, containing the first representatives of the *Hipparion* group.

c. Retaining the term "Valentine" as a group name, and applying three new names to the three horizons comprising the original Valentine beds.

It would seem that it might be advisable, because of this confusion in the use of the name "Valentine" to drop the term as a time designation, and to substitute some other less controversial name in its place when speaking of the lower or basal Pliocene of North America.

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FURTHER COMMENTS ON THE USAGE OF "VALENTINE."

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When considering the usage of various names which have been applied to faunal assemblages and sedimentary deposits in the Valentine area of Cherry County, Nebraska, it should be remembered that we are dealing with definitely distinguishable lithologic units as well as their characteristic faunas. Stirton and McGrew[1] have stated "We were unable to use stratigraphic or lithologic evidence when dealing with the faunas which occur in stream channel deposits. The lithology of some of these channels agrees superficially with that of others but they are found to contain fossils of different age." On the contrary, a study of the stratigraphy of the important collecting localities worked by the Nebraska State Museum in that area indicates that lithologic constitution may be readily used as a controlling basis for the subdivision of these sediments.

Field records in the Nebraska State Museum prove beyond doubt that the skull of *Aelurodon platyrhinus* was collected at the Valentine Quarry. The term "Valentine beds" was first used to designate the deposits from which this specimen was collected. Thus, it became possible to trace the original usage of the term to a specific locality which may be designated the type locality of the beds and their contained fauna. Inasmuch as the lower 175 to 225 feet of the Ogallala formation in this area, including those of the Valentine Quarry, form a definite and distinguishable lithologic unit, it was decided to limit the term "Valentine beds" to this portion of the section.[2]

The application of the term "Niobrara River" to these deposits and their contained fauna cannot be considered as in agreement with good geologic nomenclature. The Niobrara formation of Cretaceous age underlies this entire area. It would be very confusing to apply the name "Niobrara River" or the name "Niobrara" in any form to Tertiary deposits occur-

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[1] Stirton, R. A., and McGrew, Paul O.: "A Preliminary Notice on the Miocene and Pliocene Mammalian Faunas Near Valentine, Nebraska." This Journal, Vol. 29, No. 170, p. 128, 1935.

[2] Johnson, F. W.: "The Status of the Name 'Valentine' in Tertiary Geology and Paleontology," This Journal, Vol. 31, pp. 467-471, 1936.

Generalized Geological Section of Valentine Area, Cherry County, Nebraska.

Age	Formation	Members	Lithology	Fauna
RECENT TO PLEISTOCENE	(?)		0-150 Ft. Sand Hills, unconsolidated eolian deposits of sand. 0-20 Ft. Sand and Gravel, cross-bedded stream channel deposits.	 *Equus*
	UNCONFORMITY			
PLIOCENE	OGALLALA		0-80 ± Ft. Sands, greenish gray to light gray, soft to rather hard, locally contains deposits of volcanic ash. A 5 to 8 foot layer of sandy limestone with casts of gastropods immediately overlies the cap rock at some localities. Locally cut by deposits of channel sands.	This fauna is composite, having been collected from several different horizons above the Burge Sands. *Teleoceras* *Platybelodon barnumbrowni* *Pliohippus* *Hipparion cf. gratum* Tapiridae Camelidae *Plioceras dehlini* *Parelephas columbi*
		CAP ROCK BED	20 ± Ft. Sandstone, light to dark gray calcareous grit, massive, contains numerous fossil *Celtis* seeds. Weathers into vertical cliffs. Contains numerous fossil bone fragments in the basal portion.	
LOWER PLIOCENE		BURGE SANDS	0-30 ± Ft. Sands, gray, unconsolidated fine to coarse grained, cross-bedded channel sands. Often contains nodules and lenses of greenish clay.	Mylagaulidae Castoridae *Cynodesmus euthos* *Aelurodon* *Megabelodon lulli* *Hypohippus cf. affinus* *Hypohippus cf. matthewi* *Pliohippus* Rhinocerotidae *Hipparion* *Prosthennops* Oreodontidae *Cranioceras mefferdi*, ref. *Cosoryx furcatus*
	UNCONFORMITY			

LOWEST PLIOCENE OR UPPER MIOCENE	OGALLALA	VALENTINE BEDS	Upper Valentine beds 85-130 Ft. Sands, massive, gray to greenish gray, argillaceous, loose to compact, mostly fine grained, local deposits of cross-bedded channel sands. Contains few fossils in this area.	
			Lower Valentine beds 60-90 Ft. Sands, gray, fine to medium grained, largely unconsolidated cross-bedded channel sands. Contains some clay-ball concretions and occasional thin layers of greenish clay. Vertebrate fossils common at several localities.	Pisces Talpidae *Cupidinimus nebraskensis* Mylagaulidae *Eucastor cf. tortus* Lagomorpha *Aelurodon platyrhinus* *Leptocyon* *Bassariscus* *Pseudaelurus* Mustelidae Mastodontoidea *Hypohippus* *Merychippus cf. republicanus* *Protohippus placidus* Rhinocerotidae Tapiridae *Prosthennops xiphodonticus* Oreodontidae Camelidae C. (*Procranioceras*) *skinneri* *Blastomeryx gemmifer valentinensis* *Meryceros warreni johnsoni*
	UNCONFORMITY			
OLIGOCENE	(?) BRULE	(?)	0-85 Ft. Exposed. Clay, pinkish, silty, even textured. Forms steep sliffs along the Niobrara River near the Game Preserve. Lithologically resembles the typical Brule of northwestern Nebraska.	Apparently barren of fossils.
	UNCONFORMITY			
CRETACEOUS	PIERRE SHALE		Not exposed in Valentine area. Well exposed in Brown County.	
	NIOBRARA AND OLDER FORMATIONS		Underlying but not exposed in this area.	

ring in the same area as the older well established Niobrara formation. Leidy[3] did use the terms "Niobrara" and "Niobrara River" as broad locality names to indicate an area from which Doctor Hayden collected such Miocene fossils as *Protohippus placidus* and *Merychippus insignis,* such Pliocene forms as *Hipparion gratum* and *Cosoryx furcatus,* and Pleistocene species as indicated by *Stegomastodon* (*Mastodon*) *mirificus* and *Archidiskodon* (*Elephas*) *imperator.* He used these locality names in a most general way as one might say "these Cenozoic fossils are from northern Nebraska." Leidy most certainly did not indicate an intent to establish a new name and such application should not be used as priority usage in an effort to establish a formation or faunal name.

McGrew[4] and Meade have contested the usage of the term "Valentine" as applied to the lower deposits on the basis that most paleontologists have placed the Valentine fauna in the Pliocene. There is no doubt that Hayden's collections contained a mixture of faunas because definite collecting localities and horizons were not recorded. Therefore, any conclusions concerning the age of these composite collections necessarily contain errors. Some have placed the Valentine in the Lower Pliocene, others consider it transitional Miocene-Pliocene in age, and some paleontologists definitely place it in the Upper Miocene. That the Valentine has generally been placed in the Miocene is indicated by Scott,[5] who says, "The Valentine, which, for more than half a century, was always classed as Miocene, has recently, by some excellent authorities, been referred to the Pliocene, but to the present writer the older arrangement seems preferable" and "the whole character of the fauna seems Miocene." Inasmuch as the age of the Valentine is a controversial question it seems doubtful if the problem of names can be satisfactorily settled before it is placed on a firm stratigraphic basis. It should be remembered that[6] "The discrimination of sedimentary formations is based on the local sequence of rocks, lines of separation being drawn at points in the stratigraphic column where lithologic characters change or where there are significant breaks in the continuity of sedimentation" and "Members and coördinate subdivisions shall be named in the same manner as formations." Stirton and McGrew[7] indicated that they had no intention of naming a lithologic unit when they stated "These faunal names should not be used in any stratigraphic sense." There should be a definite relationship between the application of faunal and stratigraphic names. It would seem most desirable to name the faunas after the lithologic unit in which they occur rather than have one term for a faunal assemblage and another name for the lithologic unit in which the fossils were deposited. If more than one fauna can be distinguished in a single lithologic unit it would be preferable to establish faunal zones named after an index fossil which is characteristic of that zone.

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[3] Leidy, J.: "The Extinct Mammalian Fauna of Dakota and Nebraska." Journal Acad. Nat. Sci. Phila., Vol. VII, 2nd. Ser., pages 277, 296, 287, 173, 240, and 252. 1869.

[4] McGrew, P. O., and Meade, G. E.: "The Bearing of the Valentine Area in Continental Miocene-Pliocene Correlation," This Journal, this issue.

[5] Scott, W. B.: "A History of Land Mammals in the Western Hemisphere," pages 109 and 196, 1936.

[6] Committee on Stratigraphic Nomenclature, "Classification and Nomenclature of Rock Units." Bull. Amer. Assoc. Petrol. Geol. Vol. 17, No. 7, pages 850 and 856, 1933.

It is proposed to consider the terms "Fort Niobrara" and "Niobrara River" as obsolete and incompatible to good geologic nomenclature. The name "Valentine beds" should be retained and applied to the lower 175-225 feet of unconsolidated sands of the Ogallala formation in the Valentine area, and the contained fauna should continue to be designated as "Valentine fauna."

Inasmuch as there is agreement concerning the usage of "Burge sands" and "Burge fauna" no discussion will be included which deals with this portion of the section.

The Nebraska Geological Survey, the Nebraska State Museum and the Frick Laboratories of the American Museum of Natural History are making detailed studies of the stratigraphy and fauna of the overlying beds. Consequently, the author is in no position to apply names to these beds, including the lithologic unit informally designated as the "cap rock bed," and their included faunas. However, none of these beds nor their faunas should be referred to the Valentine.

The following section briefly describes the stratigraphy of the beds exposed near Valentine, Cherry County, Nebraska.

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[7] Stirton, R. A., and McGrew, Paul O.: "A Preliminary Notice of the Miocene and Pliocene Faunas Near Valentine, Nebraska." This Journal, Vol. 29, No. 170, p. 125, 1935.

MARACAIBO, VENEZUELA.

THE NEBRASKA STATE GEOLOGICAL SURVEY AND THE "VALENTINE PROBLEM."[1]

A. L LUGN.[2]

The writer is hesitant to enter the discussion of this vexing problem. As a matter of fact, perhaps too much already has been said and published on the subject. However, certain facts should be understood clearly, and it is the purpose of the writer to try to clarify certain matters.

Except in only rare instances, the State Geological Survey has always had complete coöperation from outside geologists representing established institutions like museums, geological surveys, etc., commercial companies, oil geologists, and many other individual geologists. There have been a few exceptions, and certain individuals have come into this state to collect fossils and make geologic observations; and then return from whence they came without making contacts with the local authorities; and prepare manuscripts and publish papers in which proposals have been made to revise portions of the geology of Nebraska, which they were incompetent to do, and which would not have been approved by the Nebraska Geological Survey. It is quite certain that there would have been no "Valentine problem" in our literature at this time if the Nebraska Survey had received the deserved coöperation from certain individuals, who made the mistake of incorrectly applying the term "Valentine" to a horizon not included in its original range. Every difficulty in connection with the present confusion of names could have been surmounted through an exchange of correspondence and the critical checking of manuscripts *before publication.*

Some confusion is inevitable when the locality, faunal, or stratigraphic use of a name is not clearly defined by its author. The Nebraska State Geological Survey is primarily concerned with the stratigraphic classification of the Tertiary lithologic units in this state. When the stratigraphic relationships are fully understood, the faunas can be properly and correctly related and named, whether the stratigraphic names or others are used. It should be understood that this survey, in determining its acceptance of stratigraphic names on the basis of priority, is making every effort to differentiate names which have been applied in a strictly stratigraphic sense from names which, while they may be older, were applied in only a geographic or faunal sense and have only locality significance for the most part, the term "Niobrara River" for example. Therefore this survey is in agreement with Mr. F. Walker Johnson[3] and Dr. George Gaylord Simpson[4] that the name "Valentine" is applied properly *only* when used for the *lower unconsolidated sands and gravels in the lower part of the Ogallala.* This survey definitely disagrees with the use of the terms "Niobrara River" (in any sense) and "Valentine" for the upper part of the section as applied by Stirton and McGrew in several papers.[5] We feel that F. Walker Johnson[6] has done a very fine piece of work and a great service in straightening out the confusion in terminology in the Valentine, Nebraska, area, and that others have only confused a situation which was not very clear to begin with.

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[1] Published by direction of the Nebraska State Geologist, Dr. G. E. Condra, Dean and Director of the Conservation and Survey Division, University of Nebraska, Lincoln, Nebraska.

[2] Geologist, Nebraska State Geological Survey; and Professor of Geology, University of Nebraska.

This survey cannot agree to the use of the term "Niobrara River" to apply to any part of the section in the Valentine, Nebraska, area because of the possible confusion with the "Niobrara" formation of Cretaceous age in essentially the same area. We feel that this is a serious and valid objection to "Niobrara River" as proposed by Stirton and others.[7] Cope[8] called attention to this same objection to "Niobrara" many years ago. Hayden collected "from the sands of the Niobrara

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[3] Johnson, F. Walker: The Status of the Name "Valentine" in Tertiary Geology and Paleontology, This Journal, Vol. 31, pp. 467-475, 1936.

[4] Simpson, George Gaylord: Glossary and Correlation Charts of North American Tertiary Mammal-Bearing Formations, Amer. Mus. of Natural Hist., Vol. LXVIII, Article III, p. 113, 1933.

[5] Stirton, R. A.: A Critical Review of the Mint Canyon Mammalian Fauna and Its Correlative Significance, This Journal, Vol. 26, pp. 569-576, 1933.

——————: A Review of the Tertiary Beavers, Uni. of Calif. Pub., Bull. Dept. Geol. Sci., Vol. 23, No. 13, pp. 391-458, 1935.

——————: Succession of North American Continental Pliocene Mammalian Faunas, This Journal, Vol. 32 pp. 161-206, 1936.

Stirton, R. A., and McGrew, Paul O.: A Preliminary Notice on the Miocene and Pliocene Mammalian Faunas Near Valentine, Nebraska, This Journal, Vol. 29, pp. 125-132, 1935.

Stirton, R. A., and Teilhard de Chardin, P.: A Correlation of Some Miocene and Pliocene Mammalian Assemblages in North America and Asia with a discussion of the Mio-Pliocene Boundary, Uni. Calif. Pub., Bull. Dept. Geol. Sci., Vol. 23, No. 8, pp. 277-290, 1934.

[6] Johnson, F. Walker: op. cit.

[7] Stirton, R. A., and McGrew, Paul: op. cit.

[8] Cope, E. D.: The Mesozoic and Cenozoic Realms of the Interior of North America, American Naturalist, pp. 445-462, 1887.

River" through Nebraska and west into Wyoming from formations of Pliocene (Ogallala) age to older Miocene, making no differentiations. He even collected Pleistocene fossils also "from the sands of the Niobrara River." Leidy[9] described Hayden's collections later, and there is no evidence in any of his statements that "the sands of the Niobrara River" ever meant anything but a general locality term. This is especially evident when it is noted that Hayden's fossils ranged in age from Miocene to Pleistocene.

Also, this survey considers it proper and expedient in some instances to retain a well established name that has long been in use and is widespread in the literature in preference to some hazy, obscure name, which by some manner might be shown to have had slightly prior usage in some little known publication, or which has not gained wide recognition and use, or has been largely abandoned. For example, it could very well be argued that the term "Devil's Gulch" should be used as a formational name in place of "Valentine," since the "Devil's Gulch" beds, even including the Burge channel member, are exactly equivalent to the Valentine formation, and the name was applied by Barbour[10] in 1914. Apparently most of the Devil's Gulch fossils until very recently were collected from the upper part of the exposures, mainly the "Burge" and "cap rock bed" horizons—the Pliocene part of the section, in Devil's Gulch in northeastern Brown County, Nebraska. This accounts for the general classification of the Devil's Gulch *beds* as of Pliocene age while the Valentine *beds* have commonly been referred to the Miocene, because the "Valentine fauna" has been collected from lower down, perhaps at least 100 feet lower, in the exposures—the Miocene(?) part of the section, at Valentine, Nebraska.[11]

The Nebraska State Geological Survey has tried to settle on a nomenclature for its Tertiary stratigraphy which will be generally acceptable, and the units of which are mappable. Obviously all of the faunal names cannot be applied as stratigraphic names, and only the names which apply to mappable units can survive as formational or group names, regardless of the original application of any name. This is especially true of the "Valentine," which was used by Barbour and Cook[12] in 1917, and which has been well described and defined by Johnson.[13]

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[9] Leidy, Joseph: The Extinct Mammalian Fauna of Dakota and Nebraska, Jour. of the Academy of Natural Sciences of Philadelphia, Vol. VII, Second Series, 1869.

[10] Barbour, E. H.: Mammalian Fossils from Devil's Gulch, Nebr. Geol. Survey (First Series), Vol. IV, Pt. 11, pp. 177-190, 1914.

[11] Scott, Wm. B.: A History of Land Mammals in the Western Hemisphere, pages 97, 107-112, 2nd ed., Macmillan, New York, 1937.

It is a very satisfactory stratigraphic name for all of the more or less unconsolidated, fine, gray sands, 175 to 225 feet in thickness, which constitute the lowest and oldest *formation* of the Ogallala *group*. The Valentine formation occurs under the typical Ogallala "mortar beds." The "cap rock bed," a field term mentioned by Johnson,[14] is the lowest part of the "mortar beds" division of the Ogallala group. It, the "cap rock bed," is also almost exactly the equivalent of the *Krynitzkia* fossil seed zone of Elias.[15] It contains the "upper" of Stirton and McGrew's[16] three faunas, to which they proposed to apply the name "Valentine" in a redefined sense. The Burge channel member of the Valentine formation occurs at the very top of the Valentine below the *Krynitzkia* seed zone, and the true "Valentine fauna" comes from lower down in the formation (at about 80 feet above the Valentine-Brule clay contact southeast of Valentine, Nebraska).

The "mortar beds" division of the Ogallala group, which in the main is the only part exposed in the "type locality" (?) near Ogallala, Nebraska, as defined by Elias,[17] is now to be known as the Ash Hollow formation, 100 to 250 feet thick. It contains the "cap rock bed" of the *Krynitzkia coronoformis* fossil seed zone, the "fragmental" vertebrate fossil zone (the third and highest faunal zone of Stirton and McGrew,[18] mistakenly called by them "Valentine") in the lower part of the formation. The remainder of the Ash Hollow formation includes most of the *Biorbia fossilia* fossil seed zone of Elias.[19] This part of the formation also contains several other faunal zones; and in the Valentine, Nebraska, area, near Burge, farther east in northeastern Cherry County, northern Brown County, and in Keya Paha County, the lower part of the *Biorbia* zone contains an abundant vertebrate fauna, which is higher than any mentioned by Stirton and McGrew.[20] The association of *Biorbia fossilia* with this higher fauna was discovered by Morris Skinner and the writer in 1935. Correlative faunas to the two in the lower part of the Ash Hollow formation in the Valentine, Nebraska, area and other still higher faunas are known from other areas in southern and southwestern Nebraska.

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[12] Barbour, E. H., and Cook, Harold J.: Skull of *Aelurodon platyrhinus,* sp. nov., Nebr. Geol. Survey (First Series), Vol. VII, Pt. 19, pp. 173-180, April, 1917.

[13] Johnson, F. Walker: op. cit.

[14] Johnson, F. Walker: op. cit. pp. 472-473.

[15] Elias, Maxim K.: Grasses and Other Plants from the Tertiary Rocks of Kansas and Colorado, Bull. of the Uni. of Kans. Geol. Survey, Vol. XXXIII, No. 10, 1932.

————: Tertiary Grasses and Other Prairie Vegetation From High Plains of North America, This Journal, Vol. 29, pp. 24-33, 1935.

Chaney, Ralph W., and Elias, Maxim K.: Late Tertiary Floras from the High Plains, Carnegie Inst. of Washington, Pub. No. 476, pp. 1-72, 1936.

[16] Stirton, R. A., and McGrew, Paul: A Preliminary Notice on the Miocene and Pliocene Mammalian Faunas Near Valentine, Nebraska, This Journal, Vol. 29, pp. 125-132, 1935.

[17] Elias, Maxim K.: A personal communication quoted by Stirton, R. A., Succession of North American Continental Pliocene Mammalian Faunas, This Journal, Vol. 32, pp. 177-178, 1936. See also Hesse, Curtis J.: A Vertebrate Fauna from the Type Locality of the Ogallala Formation, Bull. Uni. of Kans., Vol. XXXVI, No. 8, pp. 79-117, 1935.

[18] Stirton, R. A., and McGrew, Paul: op cit.

The third formation of the Ogallala group is now known as the Sidney gravel formation from occurrences at Sidney, Nebraska. It ranges in thickness from 15 to 50 feet; and it is widespread in southwestern Nebraska, northeastern Colorado, and in parts of western Kansas. It is the upper part of the *Biorbia* fossil seed zone.

A fourth and uppermost formation of the Ogallala group is to be known as the Kimball formation from its typical occurrence at the highest remnant levels of the High Plains in Kimball County, Nebraska. The thickness of the Kimball formation ranges from 30 to 40 feet when present in its full development; and it consists of silt, clay, fine sand more or less cemented with caliche, with one or two algal limestone beds at the very top. It is pinkish to reddish in color. It contains the fossil seeds of the genera *Echinochloa, Panicum,* and also *Biorbia.*[21] The most striking feature of this formation is the occurrence at the very top of an algal limestone (*Chlorellopsis bradleyi* Elias).[22] The formation is also widespread in its occurrence.

It should be noted at this point that it now seems evident that the typical "Snake Creek" formation, or at least the so called "upper Snake Creek," is definitely correlative with some part of the upper Ogallala group. Unfortunately "Snake Creek" has been incorrectly applied to beds, mainly channel fills, as late as Pleistocene, and also to other beds as old as

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[19] Elias, Maxim K.: same citations as under note 14.

[20] Stirton, R. A. and McGrew, Paul: op. cit.

[21] Elias, Maxim K.: op. cit.

[22] Elias, Maxim K.: The Geology of Wallace County, Kansas, Bull. Kans. Geol. Survey, No. 18, pp. 136-141, 1931.

Miocene. Much of the Miocene "Snake Creek" or perhaps the so called "lower Snake Creek" seems to be in part not Snake Creek at all but simply Sheep Creek beds in place and in proper stratigraphic sequence. Also, many of the Miocene and "Sheep Creek" vertebrate fossils which have been collected from "Snake Creek" channel deposits have come from very large blocks of Sheep Creek formation, which were broken away from the banks of the Snake Creek streams. These large blocks of rock have dimensions of ten to 20 or more feet and were never broken up or disintegrated by the Snake Creek rivers. They simply lie buried in the younger silt and sand, the true Snake Creek sediment.

The old Ogallala *formation,* as indicated in the above discussion, is now to be redefined as a *group* consisting of four definite and mappable formations. The formational names: Valentine, Ash Hollow, Sidney, and Kimball were not the choice of the present writer alone, nor of any one individual. These names were agreed upon first in conference early in March 1936 in the State Geologist's office at Lincoln, Nebraska, by the following: Dr. G. E. Condra, State Geologist of Nebraska; Dr. R. C. Moore, State Geologist of Kansas; Mr. Maxim K. Elias, Kansas State Geological Survey, and the writer. Agreement on Ogallala nomenclature also had been reached with Mr. C. Bertrand Schultz, Assistant Director (in charge), Nebraska State Museum. The Ogallala formations now have been mapped areally in detail by the Nebraska State Geological Survey; and a bulletin will be published soon which will contain these maps and a general and somewhat detailed survey of the stratigraphy of all of the Tertiary system in Nebraska. The acceptable stratigraphic nomenclature will be described. All names used have now been approved by the United States Geological Survey.

A skeleton table of the Tertiary stratigraphic divisions now acceptable in Nebraska and Kansas, and also in adjoining regions of the Great Plains, is included below. No extended discussion or elaborate citation of references can be included here. The Tertiary of this region is divisible into *four* natural lithologic *groups,* each of which represents a separate and distinct cycle of sedimentation. The White River, Arikaree, and Ogallala are familiar terms. The White River group remains unchanged. The Arikaree group has been redefined to include the Gering formation as the basal channel development at the beginning of the Arikaree cycle of sedimentation. This redefinition of the Arikaree has already been announced by Schultz.[23] The Ogallala is redefined as noted above. The Hemingford group is a new division suggested by C. Bertrand Schultz, Assistant Director, Nebraska State Museum, and concurred in by this survey. This is the first publication of the new term. The Hemingford group includes the Marsland and Sheep Creek formations. The Marsland formation is a recent term given by Schultz.[24] The basis for the use of the term Marsland and the redefinition of the Arikaree has been given fully by Schultz.

It seems appropriate to add here that the Harrison formation is to be understood in the sense in which it was originally defined by Hatcher.[25] The Marsland formation, the buff to reddish-brown beds which overlie the Arikaree group, were never included in the Harrison formation of Hatcher. Neither was the Marsland a part of Scott's "Nebraska Beds" as Hatcher thought, nor was it ever included in Darton's Arikaree.[26] Therefore these buff to reddish-brown beds never have had a proper name until the term Marsland was proposed recently. The application of the name "upper Harrison" to these beds by Peterson[27] and many others in more recent years has been unfortunate, because these beds (Marsland) have no very close stratigraphic or faunal relation to the true Harrison (in the Hatcher sense), and they are separated from the underlying Harrison formation by the most significant and important structural and erosional unconformity in western Nebraska.

It is hoped that these notes, including the table of Nebraska Tertiary stratigraphic divisions, will be helpful to all; and that the explanations pertaining to the "Valentine problem" may lead to the realization "that some agreement must be reached in this question of names" and the consummation of this end. It is hoped that this discussion and the companion papers in this number of this Journal will definitely correct the recent mis-use of the term Valentine.

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[23] Schultz, C. Bertrand: The Miocene of Western Nebraska, This Journal, Vol. 35, pp. 441-444, 1938.

[24] Schultz, C. Bertrand: op. cit.

[25] Hatcher, J. B.: Proc. Am. Phil. Soc., Vol. 41, No. 169, pp. 115-119, 1902. See also Schultz: op. cit.

[26] Darton, N. H.: Geology and Water Resources of Nebraska West of the One Hundred and Third Meridian, U. S. Geol. Survey, Prof. P. 17, p. 17, 1903. See also other papers by Darton, and Schultz: op. cit.

[27] Peterson, O. A.: Annals Carn. Mus., Vol. 4, pp. 21-24, 1906. See also, Schultz: op. cit.

TERTIARY FORMATIONS OF NEBRASKA

PLIOCENE

1. Ogallala group 300'-500'
   - (1) Kimball formation 30'-40'
     Echinochloa, Panicum, and *Biorbia* fossil seeds, and Algal limestone.
   - (2) Sidney gravel formation 15'-50'
     Upper part of *Biorbia* seed zone.
   - Snake Creek channels 0'-75'
   - (3) Ash Hollow formation 100'-250'
     Main part of *Biorbia* fossil seed zone, and several faunal horizons in *Biorbia* zone; *Krynitzkia* seed zone in the lower part ("cap rock bed"), "fragmental" vertebrate fossil zone ("Valentine" of Stirton and McGrew).
   - (4) Valentine formation 175'-225'
     Stipidium fossil seed zone; Burge channel member and the "Burge" fauna at the top; The *true* Valentine fauna occurs well down in the formation.

(?) UNCONFORMITY

MIOCENE

2. Hemingford group 250'-350'
   - (1) Sheep Creek formation 140'
     Stipidium and *Berriochloa* fossil seeds.
     Unconformity
   - (2) Marsland formation (old "Upper Harrison") 125'-200'

UNCONFORMITY

Note: Horizon of the folding of the Agate Anticline and many other structures.

3. Arikaree group 700'-800'
   - (1) Harrison formation 200'
     Daemonelix beds at the top.
   - (2) Monroe Creek formation 375'
   - (3) Gering formation 100'-200'

UNCONFORMITY

OLIGOCENE

4. White River group 500'-700'
   - (1) Brule clay formation 500'-600'
     Leptauchenia and Oreodon beds with zones of channel sandstones.
   - (2) Chadron formation 50'-150'
     Titanotherium beds.

UNCONFORMITY

Mainly Cretaceous shale formations: Pierre, etc.

NOTE: *Celtis* seeds occur throughout all of the Tertiary formations noted above. *Celtis hatcheri* has been described as from the White River group; most of the *Celtis* stones from higher formations are generally referred to the species *willistoni.* The genus *Stipidium,* perhaps several species, occurs also in the higher formations of the Ogallala group associated with the "index" fossil seeds of these zones. The Miocene-Pliocene contact is still undecided upon as indicated above.

NEBRASKA STATE GEOLOGICAL SURVEY,
LINCOLN, NEBRASKA.

SCIENTIFIC INTELLIGENCE.

PHYSICS.

Electron and Nuclear Physics; by J. BARTON HOAG. Pp. ix, 502; 274 figs., 16 tables. New York, 1938. (D. Van Nostrand Co. $4.00)—This revision and extension of the author's book *Electron Physics,* which appeared in 1929, will be welcomed by teachers of advanced undergraduate laboratory work. As the title implies, the original volume has been extended and brought up to date by an excellent selection of material relating to the physics of recent years. In so doing the author has with his former ingenuity adapted many experiments involving current research technique to the ability and experience of the advanced undergraduate student. There is surely no better method of stimulating an already awakened interest in physics on the part of a student than by affording him an opportunity to perform in simplified fashion pioneer experiments in the subject, particularly when these experiments involve comparatively recent discoveries, such as Laue photographs, electron diffraction, absorption of cosmic rays, and the artificial transmutation of lithium. As before, each chapter starts with an introduction leading to the theory underlying the subsequent one to five experiments on the topic in question. There is a chapter on vacuum technique, and one on high voltage technique. At the end of the book there are eight pages of problems which the author has found useful in leading to an understanding of the principles involved. A. T. WATERMAN.

CHEMISTRY.

Numerical Problems in Advanced Physical Chemistry; by G. H. WOLFENDEN. Pp. xx, 227. Oxford, 1938 (Clarendon Press, $2.75).—This book is designed to bridge partially, by the use of problems, the gap between theoretical physical chemistry and modern laboratory practice. In the opinion of the reviewer the book meets a very real need.

The book consists of 133 problems, based on original papers which have appeared in the journals in recent years. References to the original papers and helpful notes are given with each problem. In general the author has chosen problems that illustrate the principle involved with a minimum amount of irrelevant calculation. Problems involving a comparatively large amount of numerical calculation are marked with an asterisk. A complete set of answers to the problems is given, and, in the case of longer problems, answers to intermediate stages of the calculation are given. An excellent feature of the book is an analytical table in which each problem is related to the relevant chapter of a selection of twelve widely used text books. A table of the more important constants and conversion factors together with their logarithms is also given.

The distribution of the problems among the various fields of physical chemistry is as follows: Fundamental Constants (5); Stoichiometry (5); Gaseous Equilibrium (8); Heterogeneous Equilibrium (11); Thermochemistry and Miscellaneous Thermodynamics (11); Conductivity of Solutions and Transport Numbers (7); Equilibria in Solution (21); Miscellaneous Electrochemistry (24); Photochemistry (6); Molecular Structure (21); Crystal Structure (6); Radioactivity (9).

It is evident that the author has taken considerable care in choosing problems that are both practical and stimulating. Such a set of problems should be a valuable asset to any graduate course in Physical Chemistry. Selected problems from the book would be suitable for undergraduates in schools where the better students are encouraged to do some work in advanced physical chemistry.

R. P. SMITH.

GEOLOGY.

On the Palaeozoic Stratigraphy of Canning Land, Wegener Peninsula, and Depot Island (East Greenland); by G. SÄVE-SÖDERBERGH. Meddel. om Grönland, Bd. 96, No. 5, pp. 41, 2 pls., 8 text figs., 1937. - *On the Lower Ordovician Faunas of East Greenland*; by CHR. POULSEN. Ibid., Bd. 119, No. 3, pp. 72, 8 pls., 18 text figs., 1937.—Säve-Söderbergh made two brief visits to the difficult region mentioned in the title of his paper, and determined the stratigraphic and faunal sequence of the late Middle and Upper Devonian (Old Red facies with fishes), the freshwater Lower Carboniferous with *Asterocalamites scrobiculatus*, and the marine Permian. The Devonian strata are correlated with those of Scotland and the Baltic states.

Poulsen describes the fossils from the Cass Fjord formation, enumerating 20 forms of which half are named; the trilobites number 9, 5 of which are new, and they are of Lower Ordovician age. The next younger formation is the Cape Weber, with 21 forms, 11 of which are specifically named, 10 are new, and 9 are trilobites; this formation belongs to the late Lower Ordovician. The Narwhal Sound formation has but a few fossils, which appear to indicate Chazyan time.

CHARLES SCHUCHERT.

Die Stratigraphische Stellung des Trogkofelkalkes; by FRANZ HERITSCH. N.Jahrb.f.Min., etc., Beil.-Bd. 79, Abt.B, pp. 63-186, pls. 3-8, 2 text figs., tables, 1938.—Less than a decade ago, Fredericks of Russia made several correlations that have not stood the test of time, and among them was his reference of the Trogkofel of the Karnian Alps to the time of the Russian Gschelian. In the paper under review, Heritsch restudies the brachiopods of the Trogkofel formation (86 species, 70 with specific determinations), and reviews the correlations made on the basis of the ammonites and tetracorals. His conclusion is that the Trogkofel is not only clearly of the Permian but holds the time of the Middle Permian, i.e., of the Leonard-Hess and the lower half of the Word of Texas. He also holds that Schuchert placed the Rotliegende of Germany too low in the Permian, and correlates it here with the Uralian, Artinskian, and Kungurian of Russia. Heritsch is to be congratulated on his brilliant results, and on his clear presentation of the correlation of the more important Permian sequences of Europe, as shown in tabular form on pages 156, 158, 165, and 167.

CHARLES SCHUCHERT.

Permische Ganoidfische aus Ostgrönland; by HERMANN ALDINGER. Meddel. om Grönland, Bd. 102, No. 3, pp. 392, 44 pls. (atlas), 105 text figs., 1937.—This important morphologic work describes in great detail and illustrates 10 species (7 new) of well preserved ganoid fishes, in 7 genera (3 new), arranged in 6 families. They occur in Middle Permian calcareous concretions and limestone lenses of the Cape Stosch coast of East Greenland. These "Posidonomya" shales are correlated with the Phosphoria formation and the upper part of the Leonard formation of the United States.

CHARLES SCHUCHERT.

Der Sedimentstreifen des Lindi-Kilwa-Hinterlandes; by EDWIN HENNIG. Palaeontographica, Suppl. VII, 2. Reihe, II, pp. 99-186, 3 pls., 26 text figs., 1937. *Die Foraminiferen der Kreide- und Tertiärschichten im südlichen Deutsch-Ostafrika*; by HELMUT FAHRION. Ibid., pp. 187-216, 7 text figs., 1937.—Attention is directed to this memoir by Doctor Hennig, which concludes his description of the stratigraphy and correlations of the German East African Jurassic and Lower Cretaceous formations. In this Jurassic occur the wonderful dinosaur faunas that remind one so strikingly of the American Morrison assemblages. The author sees no general break in these deposits of the Tendaguru, and holds that the different members are but facies interfingerings of marine and continental strata, resulting from four different spreadings of the ocean over the margins of the continent. Hennig also describes 8 forms (1 new) of ammonites, 3 (1 new) gastropods, 20 (3 new) bivalves, 3 (1 new) brachiopods, and 1 arthropod.

CHARLES SCHUCHERT.

Middle Devonian Corals of Ohio; by GRACE ANNE STEWART. Geol. Soc. America, Special Paper No. 8, pp. 120, 20 pls., 1938.—We have long needed a good review of the Tabulata and Tetracoralla of the Middle Devonian of Ohio, and we are grateful that one is now at hand. The author notes that the forms already in the literature number 120. Her present work describes 20 new ones, but recognizes 96 named forms in 30 genera; one genus is new, *Schistotoecholasma,*—a rather cumbersome name. It is the Columbus limestone that is so rich in corals, having 78 forms, 61 of which are restricted to the formation. This richness of forms, however, extends only through 20 miles in central Ohio along or near the Scioto River. CHARLES SCHUCHERT.

Methods in Paleontology; by CHARLES L. CAMP and G. DALLAS HANNA. Pp. 153, 58 figs., Univ. of California Press, 1938 ($2.50).—We took up the reading of this little book with great expectations, but soon found that we had been misled somewhat by the title. It is a handbook on the collection and preparation of fossils for study and exhibition, and thus viewed, it is an excellent book and one that will be helpful to all beginners in Paleontology and to many old-timers in this science. Part One (74 pages), by Professor Camp, who also wrote the Introduction, treats of the vertebrates; and Part Two (53 pages), by Doctor Hanna, is on invertebrates. One is astonished at the length of the Bibliography, which includes 196 titles. The three pages on Paleobotany are altogether too brief, and we hope to see them expanded in the next edition to a length worthy of this science. There are many photographs and line sketches to illustrate field occurrences and tools and apparatus used in collecting and cleaning fossils.

CHARLES SCHUCHERT.

Boletin de Geologia y Mineria, Venezuela, vol. I, Nos. 2-4, pp. xi, 288, with geologic map of Venezuela and other maps and sections, Caracas, 1938.—This is the English edition of the papers presented at the First Venezuelan Geological Congress, held at Caracas in February, 1937. It has fourteen papers, eight of which are stratigraphic, one paleontologic, and the rest pertain to general geology. The translations were made by members of the Venezuelan Geological Survey, and "as there are no exact Spanish equivalents of some English geological terms and there are not exact English equivalents of some Spanish geological terms," we find here a number of new words for the English language. And as the linotypers do not "speak English," there are naturally many typographical errors. However, we are thankful for this English edition, which will make more widely known the results of the Venezuelan congress, for which the theme chosen was the stratigraphy of that country. We congratulate the Ministerio de Fomento and Secretary Guillermo Zuloaga on their good results, and we hope that the fostering of geologic knowledge in Venezuela will be continued. CHARLES SCHUCHERT.

The Cycle of Weathering; by B.B. POLYNOV. Translated from the Russian by ALEXANDER MUIR. Pp. xii, 220; 4 figs., 10 tables, London, 1937 (Thomas Murby & Co., 10s., 6d.).—It is an unfortunate fact that many students of the soil have had little knowledge of geology; unfortunate also that geologists have paid far too little attention to the science of pedology. The Russians have been pioneers in scientific study of soils, and the author of the present volume has the great advantage that he is a mineralogist as well as a pedologist. He is equipped to discuss the broad effects of weathering from the chemical and geologic points of view.

The author defines as the *zone of weathering* that upper part of the lithosphere "within which the processes are directed toward the disintegration and comminution of rocks and the formation of the *crust of weathering*," which in turn is defined as those parts of the zone which at present are made of the loose products of weathering. All of the processes active within the zone of weathering are divided into two categories: those that involve evolution of energy and result in the most inert forms of matter; and those that involve absorption of energy and increase the degree of dispersion of material. These two sets of closely related reactions give rise to partial cycles through which the chemical elements pass; cycles that are not complete, since there is a tendency for concentration of some elements at the expense of others.

Cycles involving three important groups of elements are discussed in turn: (1) The oxygen, carbon, and nitrogen cycles. Interactions of these common elements result in some of the most characteristic compounds, including humus and other organic material. (2) The silicon, aluminum, and iron cycles, involving a complex set of reactions that give rise to some of the most characteristic features of soils and sedimentary deposits. (3) Cycles of the alkali and alkaline earth metals, chlorine, sulphur, and phosphorus. After discussing these processes, with appropriate illustrations, the author turns to "forms of the crust of weathering and their distribution," for the geologist the most valuable part of the book. Weathered products are divided into residual *eluvium* and accumulative *alluvium*. There is a further classification, which recognizes three main sources of weathered material: massive crystalline rocks, consolidated and uplifted marine sediments, and unconsolidated products of weathering on land areas that are uplifted and subjected anew to erosion. The effects of geomorphology, climate, and time are duly considered. Red-colored eluvium and alluvium are treated as a special problem, and it is stated that "the cause of the red color of laterites and of many siallitic sedimentary rocks, and of sands and sandstones, is by no means yet decided." The author points out that many soils produced by long-continued weathering in tropical regions are not red, and that on the other hand red soils have developed from calcareous rocks as far north as Leningrad.

There are a few obvious errors and questionable statements. James Hutton's work is ascribed to the *beginning* of the eighteenth century. Inclusion of the entire lithosphere in the Earth's "crust" will not meet the approval of most tectonic geologists. It is stated as a well-authenticated fact that "raindrops falling on flint which has been warmed by the sun's rays can produce cracks in it." But the book gives a broad philosophic view of the entire phenomenon of weathering, and deserves careful study. The work is a fitting introduction to a more detailed discussion of soils, which is promised in a second volume. CHESTER R. LONGWELL.

BOTANY.

Text Book of Plant Virus Diseases; by KENNETH M. SMITH. Pp. x, 615; 101 figs. Philadelphia, 1937 (P. Blakiston's Son & Co., $5.00).—Despite the title this is not a textbook but an excellent reference book in which all known plant viruses are listed with descriptions of the disease they cause. The viruses are classified according to the generic Latin name of the host, and the various ones on the same host genus are consecutively numbered 1, 2, and so forth; for example *Lycopersicum* virus 4 (tomato bushy stunt virus) and *Solanum* virus 14 (potato phloem necrosis). The treatment is uniform; the virus, its properties, mode of transmission and other characters being discussed first, followed by the diseases it causes on various hosts arranged according to plant families. One chapter is devoted to an account of the insect vectors of plant viruses. There is a list of literature cited at the end of each chapter. Of particular value to practical workers is an appendix table of the more important hosts arranged alphabetically showing the typical symptoms caused by the different viruses on them.

This is the only book of its kind, and combined with the author's earlier book, *Recent Advances in the Study of Plant Viruses*, in which problems and methods of study are discussed, forms a complete reference on plant viruses. J. S. BOYCE.

Forest Pathology; by JOHN SHAW BOYCE. Pp. vii, 600; 216 figs. New York and London, 1938 (McGraw-Hill Book Co., $5.00).—This latest addition to the American Forestry Series deals with that highly specialized branch of plant pathology which pertains to diseases of forest trees and has for its purpose the prevention and control of such diseases; a particularly difficult kind of control in that the measures used must necessarily be circumscribed by the low value of the individual tree. While written primarily as a text for the teaching of forest pathology and as a handbook for the practical forester, this book cannot be ignored by the research worker. For him it draws a timely picture of the present status of knowledge in this field. Also, the copious references which appear at the close of each chapter have been selected with such skill that they present a wealth of important subject matter without unduly lengthening the book by the intrusion of non-essential titles.

The presentation throughout is from the standpoint of the pathologist. Not once in the difficult task of compressing within so brief a space as 600 pages the enormous amount of information available, has the author digressed from this purpose. The taxonomic and morphological aspects of the mycology with which the subject is necessarily so intimately interwoven never outweigh the paramount thought of control. The book impresses its reader by a maturity of judgment born of long experience. It reflects the author's many years of activity both in government service and in university teaching. It gives a feeling of being truly national in scope in that the experience gleaned has not been restricted to any one regional viewpoint. Simply and clearly written, it presents a comprehensive review of diseases in forest trees, arranged and classified not from the standpoint of the taxonomic niche occupied by the causal organism, but according to the part of the tree attacked. Such an arrangement will be especially welcome to practical forestry workers who lack the mycological background requisite to locate easily any particular reference under the more usual taxonomic arrangement.

The book is divided into twenty-one chapters with subjects and page length as follows: Introduction—6; Disease—10; The Fungi —22; Noninfectious Diseases—36; Seedling Diseases—34; Root Diseases—29; Foliage Diseases of Hardwoods—25; Foliage Diseases of Conifers—42; Stem Diseases: Rusts of Conifers—23; Stem Diseases: Rusts of Conifers (Continued) White Pine Blister Rust—22; Stem Diseases: Cankers of Conifers—23; Stem Diseases: Cankers of Hardwoods—45; Stem Diseases: Galls and Witches' Brooms—8; Stem Diseases: Diebacks and Wilts—18; Stem Diseases Caused by Mistletoes, Dwarf Mistletoes, Epiphytes, and Climbers—25; Stem Diseases: Decay—48; The Rots—69; Deterioration of Dead Timber—14; Deterioration of Forest Products: Decay—22; Deterioration of Forest Products: Sap Stains—20; Principles of Forest Disease Control—22. R. P. MARSHALL.

BIOLOGY.

Life, Heat, and Altitude, Physiological Effects of Hot Climates and Great Heights; by DAVID B. DILL. Pp. xiv, 211; 25 figs. and 27 tables. Cambridge, 1938 (Harvard University Press; $2.50).—Based upon his experience at the Harvard Fatigue

Laboratory, in deserts and high mountains, as well as at selected locations near the sea-shore and at industrial plants, the author writes with authority for the physiologist, physician, and biochemist, and also with a simplicity which will fascinate the aviator, naturalist and layman.

After an explanation of the relations of energy exchange to environment, the physiology and modification of thirst and perspiration under various conditions are discussed. Then follow chapters on man's reactions to both humid and dry hot climates, and on animal life in deserts and at great heights, both terrestrial and aerial. One of the most fascinating chapters gives a vivid picture of the discomforts that the members of the Fatigue Laboratory party suffered in the high Andes, and their partial accommodation to the low oxygen content of the air. Interesting is the status of vicuñas and llamas, animals native to high Andean regions; for their hemoglobins are inherently different from those of other animals in affinity for oxygen. Man and dog become adapted to this "rarefied" air, but cats do not. Even the burro owes his comfort to a refusal to be pushed beyond the limits of his endurance.

The author and his co-workers have found that at sea-level differences in the amount and character of perspiration, as well as in the efficiency of the circulatory and respiratory systems of different men, are useful earmarks which differentiate "the potentially successful man at high altitude from his fellow who is certain to suffer," for every physiological function is sure to be impaired when the oxygen supply is reduced.

Particularly appropriate at this time is the final chapter on high altitude flight. While much is heard of pilot error and fatigue, little information is at hand about the physiological background. "Research in this direction is in a primitive state as compared with the advanced stage which aeronautical engineering has reached."

S. C. BALL.

A Laboratory and Field Guide to Biology; by SAMUEL WILLIAMS. Pp. xxv, 130; 1 fig. New York, 1938 (The Macmillan Co., $1.25).—Designed to provide a working method for Nature Study, Field Biology, and General Biology, in the hope of encouraging more out-of-door work and pleasure on the part of students in cultural biological courses. The author writes with the conviction born of experience; his unusual little book should go far in helping to attain what all biologists agree is desirable—a closer acquaintance with our living environment. S. C. BALL.

Manual for Comparative Anatomy; by LEONARD P. SAYLES. Pp. xi, 214; 55 figs. New York, 1938 (The Macmillan Co., $1.60).—Planned on the year's course in Vertebrate Anatomy at The City College of New York, this manual is unique in its field, both in its loose-leaf format and the excellence of the line drawings which illustrate the selected chordate types. Stress is placed on dissections and practical examinations, rather than upon drawings. Thus students are enabled to cover much ground, and certain ones undoubtedly will profit by freedom from labor for which they are unfit. The arrangement of successive steps is fortunate; the typography is clear; and the book is well suited to convenience at the laboratory table. S. C. BALL.

Animal Biology; by LORANDE LOSS WOODRUFF. 2nd edition. Pp. xiv, 535; frontispiece and 312 figs. New York, 1938 (The Macmillan Co., $3.75).—In revising this well known text-book the author has incorporated numerous changes, especially in the field of genetics, and has added a useful chapter on the human background. But the plan remains the same, and in the sections referred to in Baitsell's *Manual of Animal Biology* the page and figure numbers have not been changed. The author has wisely adhered to the plan which has been so successful in his *Foundations of Biology,* convinced that the general biological viewpoint affords the best approach to an introductory survey of either animal or plant science.

The bibliography has been brought up to date with references to many recent scientific books. S. C. BALL.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

A Black Civilization; a Social Study of an Australian Tribe; by W. LLOYD WARNER. Pp. xviii, 594; 17 illustrations, 16 charts, 3 figures, map. New York and London, 1937 (Harper and Brothers, Publishers, $5.00).—This comprehensive monograph brings from obscurity into the limelight eight tribes located in the northeastern corner of Arnhem's Land and collectively denominated "Murngin." There are good accounts of industry and warfare, a critical examination of Malay influence, an extensive compilation of folkways and an impressive correlation of myth with ritual, illumined by numerous native interpretations. These portions of the work merit the praise accorded in Doctor Lowie's preface.

On the other hand, the treatment of the social organization is marred by inaccuracies and contradictions and appears inadequate. There is indeed a well executed kinship schema, followed by a detailed discussion of kinship behaviour. The discrimination of clan kinship as a category distinct from genealogical kinship and tribal kinship is praiseworthy. But the kinship system, which is altogether exceptional in requiring one set of kinsmen to pass sisters as wives to a second, who give to a third, etc., through seven kin lines, fails to show what eighth group, recipient from the seventh, donates to the first. Nor is it clear by what process the clans, which depart from the continental pattern in bearing two kinship lines, may effect the interchange of women within four or less clans.

The data suffice to show that the "sub-section" system is radically off type but fail to elucidate. Deficient in patrilineal descent, Chart VII is useless, while Chart VIII is unintelligible, and Chart XVI is incomplete. The seeming articulation of each kinship term in Chart II with two sub-sections is misdescriptive, being accomplished by the inadmissible location of Ego in two sub-sections simultaneously.

Strictures do not belittle the significance of Professor Warner's contribution. There can be no doubt that the wealth of lore assembled in three years' residence among the Murngin is priceless. WILLIAM E. LAWRENCE.

OBITUARY NOTES.

PROF. RAYMOND L. BARNEY, professor of biology at Middlebury College, died on July 9 at the age of forty-six.

DR. EDWARD FULLER BIGELOW, educator, naturalist, writer and lecturer, died on July 13 at the age of seventy-eight. He was president of the Agassiz Association, and curator of the Bruce Museum at Greenwich, Conn. Natural history excursions for more than 100,000 boys and girls were conducted by Dr. Bigelow in twenty-five years.

DR. ERNEST WILLIAM BROWN, Josiah Willard Gibbs professor of mathematics emeritus at Yale University, died on July 22 at the age of seventy-one.

DR. BEVERLY THOMAS GALLOWAY, head of the department of mycology in the U. S. Department of Agriculture, died on June 13 in his seventy-fifth year.

DR. ERNEST GOULDING, who retired from the service of the Imperial Institute, London, in 1935 when holding the post of vice-principal in the Plant and Animal Products Department of the Institute, died in London on February 15 in his sixty-eighth year.

DR. CHARLES HOLMES HERTY, research Chemist in charge of the Pulp and Paper Laboratory of the Industrial Committee of Savannah, Georgia, died on July 27 at the age of seventy. American chemists regarded Charles Holmes Herty as one of the greatest in their profession and demonstrated their respect for him as far back as twenty-two years ago by electing him president of the American Chemical Society. His process for turning Southern pine into newsprint opens the way to wealth for the South.

DR. JACOB KUNZ, professor of mathematical physics at the University of Illinois, died on July 18 at the age of sixty-four.

MISS A. T. NEILSON, lecturer in geology in the University of Glasgow, died on July 8.

Prof. Fernando Nevermann, since 1909 professor of entomology at the National Agricultural School of San José, Costa Rica, was recently killed accidentally on a banana plantation near Port Limon. He had one of the world's greatest collections of tropical insects, on which he is considered an authority.

Dr. Louis K. Oppitz, professor of physics at McKendree College, Lebanon, Ill., died on July 8 at the age of sixty.

Miss Edith Stoney, one of the vice-presidents of the British Federation of the University Women, died on June 25 at the age of sixty-nine. She was a mathematical physicist.

Dr. A. E. H. Tutton, F.R.S., formerly H. M. Inspector of Schools (Technological Branch), Board of Education, London, and a leading authority on chemical and physical crystallography, died on July 14, aged seventy-three.

By the death of Prof. R. Vondráček at Brno on June 12, Czechoslovakia has lost a distinguished chemist and technologist. Vondráček began his career as a research worker in pure and applied chemistry whilst completing his studies under Professor Votocěk at Prague, with whom he investigated the separation of certain reducing sugars by hydrazine. Altogether he contributed about fifty original papers to Central European periodicals and he was the author of four text-books.

PUBLICATIONS RECENTLY RECEIVED.

Mineral Tables. For the Determination of Minerals by Their Physical Properties; by A. S. Eakle. Third edition, revised by Adolf Pabst. New York and London, 1938 (John Wiley & Sons, $1.50).

Genetics; by H. E. Walter. Fourth edition. New York, 1938 (The Macmillan Co., $3.00).

A Manual for Comparative Anatomy; by L. P. Sayles. New York, 1938 (The Macmillan Co., $1.60).

A Laboratory and Field Guide to Biology; by Samuel Williams, New York, 1938 (The Macmillan Co., $1.25).

An Orientation in Science; by H. A. Alling, New York and London, 1938 (McGraw-Hill Book Co., $3.00).

Survey of Physical Science; by Paul McCorkle. Philadelphia, 1938 (P. Blakiston's Son and Co., $2.75).

Smithsonian Miscellaneous Collections. Vol. 91, No. 29. Reports of the Collections Obtained by the First Johnson-Smithsonian Deep-Sea Expedition to Puerto Rican Deep. A New Genus of Starfishes from Puerto Rico; by A. H. Clark.

Struktur und Eigenschaften der Materie. Der Smekal-Raman-Effekt. Ergänzungsband 1931-1937; von K. W. F. Kohlrausch. Pp. ix, 288; mit 27 abbildungen. Berlin, 1938 (Verlagsbuchhandlung Julius Springer RM. 24. gebunden RM. 25.60).

Kansas State Geological Survey. Vol. 39. No. 6. Water Supplies from Wells Available for Irrigation in the Uplands of Ford County, Kansas; by S. W. Lohman. Pp. 10; 1 map. Vol. 39. No. 7. Oil and Gas Resources of Western Kansas; by W. A. Ver Wiebe. Pp. 179; 24 figs. Lawrence, Kansas, 1938.

U. S. Geological Survey Water-Supply Paper 779. Geology and Ground-Water Resources of South-Central Nebraska. Pp. vii, 242; 16 plates, 21 figs. Price 70 cents.

The Scientific Journal of the Royal College of Science. Vol. VIII. Pp. 92; 21 figs. London, 1938 (Edward Arnold & Co., 7/6).

Memoirs of Sir Isaac Newton's Life; by William Stukeley. London, 1936 (Taylor & Francis, 5/-net).

Mississippi State Geological Survey. William C. Morse, Director. Bulletin 37. The Geologic History of Magnolia State Park; by W. C. Morse. Pp. 18; 12 figs., 1 plate. University, Miss., 1938.

Geological Survey of Great Britain. The Kidston Collection of Fossil Plants With an Account of the Life and Work of Robert Kidston; by R. Crookall. Pp. iii, 33; 1 plate. Price 30 cents.

The Living Body; by C. H. Best and N. B. Taylor. New York, 1938 (Henry Holt and Co., $3.60).

Chemical Kinetics; by Farrington Daniels. Ithaca, New York, 1938 (Cornell University Press, $3.25).

U. S. Geological Survey. Bulletins as follows: 877. Geology and Ore Deposits of the Bayhorse Region Custer County, Idaho; by C. P. Ross. Pp. vii, 161; 3 plates, 17 figs. Price $1.00; 884. Geology and Mineral Deposits of the Snowmass Mountain Area Gunnison County, Colorado; by J. W. Vanderwilt. Pp. viii, 184; 24 plates, 23 figs. Price $1.00; 889. Spirit Leveling in Kansas 1896-1935; by J. G. Staack. Pp. ii, 88; 1 plate, 2 figs. Price 15 cents; 895-B. Geophysical Abstracts 89 April-June 1937; compiled by W. Ayvazoglou. Pp. ii, 92. Price 10 cents; 898-A. Spirit Leveling in Missouri, Part I. Southeastern Missouri, 1896-1937; by J. G. Staack. Pp. iii, 132; 1 plate, 2 figs. Price 25 cents.

Illinois State Geological Survey. M. M. Leighton, Chief. Bulletin No. 59. The Fluorspar Industry of the United States with Special Reference to the Illinois-Kentucky District; by Paul Hatmaker and H. W. Davis. Pp. 128; 14 figs., 39 tables; Report of Investigations—No. 48. Washability Characteristics of Illinois Coal Screenings; by D. R. Mitchell and L. C. McCabe. Pp. 84; 14 figs., 18 tables. Urbana, Illinois.

Radio: A Study of First Principles; by E. E. Burns. Third edition. New York, 1938 (D. Van Nostrand Co., $2.00).

Astronomy; by R. H. Baker. Third edition. New York, 1938 (D. Van Nostrand Co., $3.75).

The Ringstrom Three Dimensional System of the Atoms (With Atomic Musical Pitches) and the Theory of Atomic Integration; by A. B. Ringstrom. Chicago, 1938 (Vega Publishing Company).

Statistical Physics; by L. Landau and E. Lifshitz. Translated from the Russian by D. Shoenberg. New York and Oxford, 1938 (Oxford University Press, $6.00).

Geological Survey of Great Britain: 2 Topographical Maps.

The Serial Universe; by J. W. Dunne. New York, 1938 (The Macmillan Co., $2.00).

Studies on the Periodicity of Earthquakes; by Charles Davison. London, 1938 (Thomas Murby & Co., 13/6d).

Geological Survey of India. Vol. 73. Pt. I. Pp. 161; 2 figs., Calcutta, 1938. Price Rs. 3.

Insects of Citrus and other Subtropical Fruits; by H. J. Quayle. Ithaca, New York, 1938 (Comstock Publishing Co., $5.00).

General Physiology; by P. H. Mitchell. Third edition. New York and London, 1938 (McGraw-Hill Book Co., $6.00).

Laboratory Manual of General Physiology; by P. H. Mitchell and I. R. Taylor. New York and London, 1938 (McGraw Book Co., $1.50).

U. S. Geological Survey: 30 Topographical Maps.

Vegetation of South Africa; by R. S. Adamson. London, 1938 (British Empire Vegetation Committee, 10s).

The Soils of Palestine. Studies in Soil Formation and Land Utilization in the Mediterranean; by A. Reifenberg. Translated by C. L. Whittles. London, 1938 (Thomas Murby & Co., 14/).

The Genus Septobasidium; by J. N. Couch. Chapel Hill, 1938 (The University of North Carolina Press, $5.00).

U. S. Geological Survey. Bulletins as follows: 874-C. Geology and Fuel Resources of the Southern Part of the Oklahoma Coal Field. Part 3. Quinton-Scipio District; by C. H. Dane, et al. Pp. v, 253; 15 plates, 4 figs., Price 65 cents; 886-D. Preliminary report on the alunite Deposits of the Marysvale Region, Utah; by Eugene Callaghan. Pp. iv, 134; 1 plate, 3 figs., Price 15 cents; 888. Spirit Leveling in Vermont 1896-1935; by J. G. Staack. Pp. ii, 155; 1 plate, 1 fig., Price 20 cents; 895-C. Geophysical Abstracts 90 July-September 1937; compiled by W. Ayvazoglou. Pp. ii, 136, Price 10 cents; 899-A. Structure and Gas Possibilities of the Oriskany Sandstone in Steuben, Yates, and Parts of the Adjacent Counties New York; by W. H. Bradley and J. F. Pepper. Pp. iv, 68; 4 plates, 7 figs., Price 35 cents. Water-Supply Paper 796-F. Geology and Ground-Water Resources of the Valley of Gila River and San Simon Creek, Arizona; by M. M. Knechtel. Pp. iv, 222; 5 figs., 9 plates. Price 35 cents.

Elementary Survey of Physics. A Non-Mathematical Presentation with a Special Supplement for Pre-Medical Students; by A. E. Haas, with the collaboration of I. M. Freeman. New York, 1938 (E. P. Dutton & Co., $1.90).

A Hundred Years of Astronomy; by R. L. Waterfield. New York and London, 1938 (The Macmillan Co., $5.75).

Evolution; Essays on Aspects of Evolutionary Biology. Presented to Prof. E. S. Goodrich on his Seventieth Birthday; edited by G. R. de Beer. New York and London, 1938 (The Oxford University Press, $5.00).

U. S. Geological Survey, 16 Topographical Maps.

General Zoology; by H. L. Wieman. Third edition. New York and London, 1938 (The McGraw-Hill Book Co., $3.50).

Mathematical Biophysics. Physcomathematical Foundations of Biology; by Nicolas Rashevsky. Chicago, 1938 (The University of Chicago Press, $4.00).

Introductory Qualitative Analysis; by W. C. Vosburgh. Revised edition. New York, 1938 (The Macmillan Co., $2.25).

Festschrift zum 60. Geburtstage von Professor Dr. Embrik Strand. Vol. IV. Pp. 784; 16 plates, 203 figs., Riga, Latvija, 1938.

International Encyclopedia of Unified Science. Volumes I and II: Foundations of the Unity of Science. Volume I. No. 1. Encyclopedia and Unified Science; by Otto Neurath, Niels Bohr, et al. Pp. viii, 75. Volume I. No. 2. Foundations of the Theory of Signs; by C. W. Morris. Pp. vii, 59. Chicago, 1938 (The University of Chicago Press. It is planned to publish 20 monographs in two volumes between June, 1938, and August, 1939. The price for the series is $18.00. The monographs will be available singly at $1.00.

The University of Missouri Studies. A Quarterly of Research. Contents: Distance Geometries. A Study of the Development of Abstract Metrics; by L. M. Blumenthal, with an Introduction by Karl Menger. Pp. 145. Columbia, Mo., 1938 (The University of Missouri, $1.25).

AMERICAN JOURNAL OF SCIENCE

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THE RADIUM AND RADON CONTENT OF PACIFIC OCEAN WATER, LIFE, AND SEDIMENTS.

ROBLEY D. EVANS, ARTHUR F. KIP, AND E. G. MOBERG.

ABSTRACT.

We have measured the radium content of sea water from the Pacific and Atlantic coasts of the United States. In all cases the results are several orders of magnitude lower than those obtained by previous workers. Instrumental reasons are given for regarding the lower results (ca. 10^{-16} g Ra per cc) as correct. A large increase in radium concentration with depth in the ocean has been found at several stations. This suggests that radium is being continuously precipitated out of the ocean. The bottom mud in quiet deep water shows a high radium content, mainly due to high radioactivity of the finest particles in the sediment. These fine particles are possibly organic, and as further evidence that biochemical precipitation processes play an important rôle in ocean chemistry, the radium content of a few marine plants and animals is shown to be the order of 100 times that of the water in which they live. The oceans must be more widely sampled and many more analyses must be made before the problems of oceanic radium chemistry may be completely solved, but the general character of the results is becoming clearer.

I. INTRODUCTION.

The quantitative study of the radium content of ordinary materials has already led to significant new results in the geological and cosmological sciences. Radium occurs in minute amounts as a contaminant in substantially every type of material found in, on, or above the earth. It is well established that ordinary igneous rocks contain on the average, the order of 1 x 10^{-12} grams of radium per gram. Ocean-bottom sediments, however, usually contain several times this amount of radium. The average values for terrestrial and ocean-bottom sediments are sufficiently different to leave no doubt regarding the reality of the higher average radium content shown by the deep-ocean sediments.

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Between 1907 and 1911 knowledge of the radium content of ocean water was sought in an effort to explain the penetrating radiation observed in ionization chambers operated on ships at sea. The radium analyses of ocean water by Eve,[1] Joly,[2] and Satterly[3] and the emanation analyses by Knoche[4] gave sufficiently low values to show clearly that the penetrating radiation at sea is too large to be due to oceanic radioactivity. The subsequent discovery of cosmic rays provided a satisfactory explanation of the ionization over the sea, and little further[5] experimental work on the radium content of sea water was undertaken as the World War closed down such research programs.

In recent years the oceanographic problems of radium precipitation have attracted new interest. The solution of the radium problem must bring with it new light on other phases of oceanic chemistry. During the summer of 1930 Devaputra, Thompson, and Utterback[6] carried out radium analyses on 74 sea-water specimens, mostly from the Pacific Ocean. All the early workers had found considerable variation in the radium content of ocean-water samples drawn from various parts of the Atlantic, Mediterranean, and Indian Oceans. Table I summarizes briefly the results of these investigations. Devaputra, Thompson, and Utterback are in general agreement with Joly in assigning a high radium content to the oceans, while Eve and Satterly obtained values which are about an order of magnitude lower. There is very little spread in the Devaputra-Thompson-Utterback data, suggesting that something beside the sea-water specimens contributed heavily to the observed electroscope currents.

Strutt,[7] Eve,[8] Mialock,[9] and Hewlett[10] examined salts, obtained by the evaporation of sea water, for radium, usually by the carbonate-fusion-emanation technique. These results are included in Table I.

The general conclusions regarding the radium content of the seas to be drawn from all these analyses are the following:

1. Variations due to ocean currents, depths, proximity to land, etc., probably exist.
2. The concentration of radium in ocean water is very low.
3. Because of this low concentration, the absolute magnitude of the radium concentration is difficult to determine, and hence the activities reported for similar specimens seem to depend less on their origin than on the analytical technique employed in the radium analyses.

TABLE I.

Radium Content of Ocean Water and Sea Salts, Reported by Various Observers.

Sea Water

Author and Date	General Locality	No. of specimens	Radium, in 10^{-15} g per cc	
			Range	Mean
Eve (1907)	N. Atlantic	1	6.	6.
Joly (1908)	England Arabia Mediterranean	11	20. to 390.	255.
Eve (1909)	N. Atlantic	6	5. to 15.	9.
Joly (1909)	Ireland Atlantic Mediterranean Black Sea Indian Ocean	25	20. to 340.	255.
Satterly (1911)	S. E. England	4	2. to 16.	10.
Lloyd (1915)	Gulf of Mexico	1	17.	17.
Devaputra, Thompson, and Utterback (1932)	Pacific	58	33. to 69.	50.
Devaputra, Thompson, and Utterback (1932)	Atlantic Hudson Bay	16	380. to 470.	450.
Evans, Kip, and Moberg (1937)	Pacific Atlantic	14	0.0 to 3.2	0.8

Sea Salt

			Radium, in 10^{-14} g per g
Strutt (1906)	?	1	7.5*
Eve (1907)	?	1	2.04
Mialock (1916)	Atlantic Pacific	20	150.
Hewlett (1917)	Atlantic Pacific	15	Less than 10.

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* Corrected for revised U: Ra ratio; see Eve and McIntosh, Phil. Mag., 14, 231, 1907.

II. ANALYTICAL TECHNIQUE.

In the present experiments about 50 radon analyses have been made on 31 different samples of ocean water, life, and sediments. The radium content of ocean water was found to be considerably lower than the values reported by previous workers. Accordingly, a number of special experiments were performed to make sure of the quantitative accuracy of the analyses as well as to locate the sources of errors which had led previous workers to report what seem to be fictitiously high radium concentrations.

The analytical technique developed for these measurements has been fully described by one of us.[11] The method completely excludes the effects of all radioactive substances except radon and radium, hence the uncertainty voiced by Clark[22] cannot arise here. It remains only to point out the particular difficulties encountered in precise analyses of the radium content of sea water.

Many of the water specimens were collected during the spring and summer of 1934 under the direction of Moberg, using a small boat sent out on one-day cruises for this sole purpose from the Scripps Institution at La Jolla, California. Clear, new, ground-glass-stoppered, one-liter glass bottles, specially cleaned and dried were used, together with the standard oceanographic technique for obtaining water samples for dissolved gas analysis. Two bottles were used for each sample, both being completely filled except for a few cc of air at the neck to allow for subsequent temperature changes. The boat schedule was arranged to meet the evening train, the samples being put aboard and delivered to the laboratory at Berkeley the following morning. Here the glass stopper on each bottle was replaced with an identical stopper previously drilled axially, and 1,600 cc of each sample were transferred by siphon into the evacuated radon apparatus shown in Fig. 2 of reference 11. In this way all the radon present in the water sample was available for the analysis which was immediately carried out.

This analysis, when corrected for the subsequently determined true radium content, and for the decay of free radon after bottling the sample at sea, gives the excess radon content, that is, the free radon which had been absorbed by the sea water from its environs, particularly the atmosphere and the bottom muds. This excess radon is not due to radium in the seas. The sample then remained sealed in the apparatus for about eight days, during which time the radium in the specimen rebuilds the radon to about three-quarters of its equilibrium value. This radon is then boiled off as before, and its analysis leads to the value for the true radium content of the sample. The radium measurement can of course be repeated as many times as desired at intervals of about one week, the sample having been in contact with the atmosphere at no time since it left the ocean. These precautions are necessary because the radon content of air near land masses is the order of 10^{-16} curie per cc; thus a given volume of terrestrial air contains more radon than the same volume of sea water, and the transfer of the water sample by pouring might introduce appreciable errors. The radon content of the laboratory air was $0.7 \pm 0.1 \times 10^{-16}$ curie per cc on May 24, 1934 near the middle of the present experiments.

The possibility of contamination of the sample is completely circumvented by this technique, which avoids the concentration of the sample by boiling in an open dish in the laboratory, the addition of talc and hydrochloric acid, and similar procedures used by most of the previous workers. The sample flask on the radon apparatus is cleaned between specimens by boiling HCl and $BaCl_2$ in it, and rinsing with distilled water, all of which are previously analyzed for radium and found to contain negligible amounts for the quantities used.

Several control-tests were run to determine whether or not all of the radon in the water sample is released by the reflux-boiling and nitrogen-agitating methods used. It was found that the 20 minute boiling technique, which is adequate for 250 cc samples, was not sufficient, but that a one hour boiling program removed all the radon in the 1,600 cc sample. Two hours of additional boiling then failed to yield any more radon. Secondly, a method of internal standardization was employed. To an analyzed 1,600 cc sea-water sample (No. 8493, Table V) was added 0.786×10^{-12} gm of radium from a standard solution previously compared with the International Radium Standard.[11] Repeated analysis of this water standard ($[5.0 \pm 0.2] \times 10^{-16}$ g Ra per cc) showed that the one hour boiling technique does in fact completely de-emanate the sample, and that after standing for a month no radium is precipitated in such a way as to make its radon inaccessible to further analyses. The absolute values obtained are further confirmed by the agreement between this sea water standard, the 19.66×10^{-12} gram radium standard usually employed for calibration, and the theoretical calibration[12] based only on apparatus geometry, and the decay constants and ranges of the alpha rays of radon and its decay products.

Seeking further to establish instrumental reasons for the high values reported by previous workers, we were able to reproduce fictitiously large electrometer readings by eliminating the insulation drying trays in the ionization chambers. It was definitely established that the ordinary phosphorus pentoxide drying tube in the gas line leading from the reflux condensers to the ionization chambers is insufficient to dry the gases adequately. The internal dryer located inside the ionization chamber and near the amber insulation is absolutely essential in preventing leakage currents from falsifying the electrometer readings. The absence of an internal dryer in the Lind ionization chamber used by Devaputra, Thompson, and Utterback, together with the rapidity with which their measurements had to be made, and possible under-estimates of the important effects of cosmic rays in these ionization measurements, may explain the high and uniform values they obtained.

In the present experiments the radon ionization current was usually observed for a period of 10 to 15 hours for each analysis, with an equivalent length of background interdigitated between specimens. Such long observations are made possible by the fully automatic calibrating and continuous photographic recording[11] features of the detection apparatus. They are necessary in order that the large statistical fluctuations in the emission of the alpha rays of radon and its decay products may be averaged out. Observations of a few minutes or even an hour's duration, such as characterized the visual observations of the earlier investigators, cannot disclose the magnitude of these statistical errors. Much of the non-reproducibility of the early measurements must arise from such fluctuations.

Each sample yields the order of 10^{-13} curie of radon, and therefore gives about 25 alpha rays per hour for the ionization of the gas in the ionization chamber. Since the natural and unavoidable radioactivity of the brass walls of the chamber gives about 200 alpha rays per hour, it is clear that the Poisson Law fluctuations in the resultant ionization are very appreciable. The probable errors assigned to the various results in the following section have been determined in the manner described earlier for this apparatus.[11, 13] Most of this uncertainty arises from the statistical fluctuations in the background ionization.

III. RESULTS ON OCEAN WATER AND MUDS.

A. Variation of radium concentration with depth.

The first set of ocean-water samples tested was collected February 6, 1934 at a station 13 nautical miles from Point Loma, California, the nearest point on the mainland, and nine miles north of Coronado Island, Lat. 32° 32′N, Long. 117° 22′W. Using the sampling technique described in the previous section, water samples were collected from just below the surface, from 600 meters depth, and from 1,300 meters, the last being the ocean bottom. The determination of the excess radon in the surface sample was the first analysis undertaken and its result is more uncertain than the others because only a 600 cc sample was used in view of the optimistic predictions of the previous literature. The initial radium measurements were repeated after an interval of over five months. The second values (Table II) in every case are in perfectly satisfactory agreement with the first analyses, and suggest that the probable errors assigned on a basis of the observed statistical fluctuations in ionization are essentially correct, and that no errors are present of the type assigned by Joly to sulphate precipitation.

TABLE II.

Scripps Ocean Water and Mud Specimens, February 6, 1934.
Lat. 32° 32′ N., Long. 117° 22′ W.

The second analyses indicated for the water specimens were made five months after the first runs.

Sample	Depth in Meters	Radium in 10^{-16} g Ra per cc water	Excess Radon in 10^{-18} curie per cc water
8491	0	$\begin{cases} 0.3 \pm 0.1 \\ 0.5 \pm 0.2 \end{cases}$	4. ± 2.
8490	600	$\begin{cases} 1.5 \pm 0.1 \\ 1.3 \pm 0.3 \end{cases}$	0.0 ± 0.1
8489	1300 (bottom)	$\begin{cases} 3.2 \pm 0.2 \\ 2.6 \pm 0.3 \end{cases}$	22.0 ± 0.8
8489 (Mud)	1300	3.00 ± 0.05 x 10^{-12} gm Ra per gm mud 3.17 ± 0.05	

The radium concentrations show a marked increase with water depth, amounting to nearly a factor of ten over the entire 1,300 meters, and a factor of about four over the first 600 meters.

Within the observational uncertainty of the measurements the increase is approximately linear with depth. These results suggested that some radium precipitating mechanism is active.

Fortunately the field sample bottles containing the 1,300 meter specimen each contained a few grams of very fine gray mud, which had been collected with the bottom specimens and had simply been allowed to stand in the bottom of the bottles when the water samples were siphoned into the emanation apparatus. This mud was removed, dried, weighed (8.679 g) and, as its reaction to HCl showed the presence of carbonates, the sample was baked three hours at 1,000° C to destroy the carbonates. The loss of weight on baking was 21 per cent, and the sample became pink in color. The resulting 6.884 g of material was divided into two specimens which were sealed in pyrex tubing for a month to permit the radon to come back to equilibrium with the radium. Subsequent analysis using the direct fusion furnace technique[11] gave 3.00 ± 0.05 and $3.17 \pm 0.05 \times 10^{-12}$ g Ra per gram of fresh dry mud, or an average of $3.1 \pm 0.1 \times 10^{-12}$ g Ra per g.

The radium content of this bottom mud is therefore about three or more times higher than average terrestrial formations, and this high radium concentration seems to have a rather direct correlation with the concentration gradient observed in the sea water lying over it. Also it explains the large amount of free radon shown in Table II for the bottom water. This excess radon is supplied to the water by the radium in the fine bottom mud. As might be expected, the water at the middle depth of 600 meters shows no excess radon; that is, the fresh sample contained radium and radon in their radioactive equilibrium proportions. The surface water again exhibits an excess of radon, which may be absorbed from the atmosphere.

Further studies of the variation of the radium and radon concentration with depth were made on samples collected for the purpose by R. L. Bolin, of the Hopkins Marine Station at a station (Lat. 36° 44′N, Long. 122° 01′W) 7.5 miles NW of Point of Pines on July 24, 1934. Table III summarizes the data on three specimens taken at depths of 0, 450, and 900 meters, the latter being an undetermined distance (1 to 400 m) above the bottom.

These results again display an increase of radium concentration as the depth of the water increases. An excess of radon at the

TABLE III.

Hopkins Ocean Water Specimens, July 24, 1934.
Lat. 36° 44′ N., Long. 122° 01′ W.

Sample	Depth in Meters	Chlorinity 0/00	Temperature	Radium in 10^{-16} g Ra per cc	Excess Radon in 10^{-16} curie per cc
H1	0	19.381	13.4° C.	0.4 ± 0.1	0.9 ± 0.3
H2	450	19.765	6.5° C.	0.8 ± 0.2	—0.2 ± 0.3
H3	900	19.967	4.2° C.	0.9 ± 0.3	0.0 ± 0.3

surface is again evident, while the deeper samples exhibit radioactive equilibrium between radon and radium. The deepest specimen was too far from the bottom to contain free excess radon. The lower salinity of this surface specimen suggests that it contains an appreciable amount of fresh water. River and well water usually contain an excess of free radon, which they absorb from rocks and this may be the origin of most of the excess radon observed in this surface specimen.

The same general picture (see Table IV) was given by two specimens taken June 7, 1934, from the Scripps Institution Boat, at Lat. 32° 52′5N, Long. 117° 16′8W, where the water is only 276 meters deep. Analysis of a specimen of the ocean floor material at this station is given in the next section.

TABLE IV.

Scripps Ocean Water Specimens, June 7, 1934.
Lat. 32° 52′5 N., Long. 117° 16′8 W.

Sample	Depth in Meters	Temperature	Radium in 10^{-16} g Ra per cc	Excess Radon 10^{-16} curie per cc
8497	0	19.6° C.	0.3 ± 0.3	0.7 ± 0.5
8498	137	13.4° C.	0.8 ± 0.3	0.1 ± 0.3

Measurements of the total active deposit from atmospheric thoron and radon were made by Simpson and Wright.[16] Their results show that near land areas, particularly during an offshore breeze, the ocean air differs little from that over land.

Collecting the active deposit on a long negatively charged wire, and using the arbitrary activity unit of Elster and Geitel, Simpson and Wright found values between 1 and 21, with a mean of 6, for oceanic air on the voyage of Scott's Antarctic Ship "Terra Nova" from England to New Zealand. These are the order of five per cent of typical land values, which have a mean of about 124 and a range of 52 to 256. Messerschmidt[17] made an extensive series of measurements of the radon content of the air at Halle, obtaining an average of 3×10^{-16} curie per cc, which is in qualitative agreement with unpublished measurements made by one of us at Pasadena and Berkeley, California, and Cambridge, Massachusetts, and is certainly correct in order of magnitude. The Henry's law coefficient for the distribution of radon between sea water[14, 16] at 18° C. and air is about 0.16 that is, the volumetric concentration of radon in the sea water should be about 16 per cent of the concentration of radon in the air if the two phases are in equilibrium. Assuming that the relative proportions of radon and thoron are about the same over land and ocean, that the radon content of ocean air far from land is derived from the radium in the sea, and that equilibrium is present between the radon in the water and in the air, the radium content of deep sea surface water might be expected to be about $0.16 \times (6/124) \times 3 \times 10^{-16} = 0.02 \times 10^{-16}$ g Ra per cc of sea water. It is difficult to see where this independent estimate of the mean oceanic radium concentration can be in error by a factor of 10^4, as would be required if Joly's radium results were accepted. On the other hand, the present observations are in qualitative agreement with this low estimate and in disagreement with all other previous work.

Swann's[27] measurements of the emanation content of sea air, during cruise IV of the *Carnegie,* led to values between 0.000 and 0.08×10^{-16} curie Rn per cc of air. Assuming equilibrium between sea water and air, this would suggest a radium content of the order of 0.01×10^{-16} g Ra per cc of sea water, contradicting the high oceanic radium concentrations of previous observers. (Table I.)

B. *Radium and radon content of other surface water specimens.*

Tests of the overall reproducibility of the sampling, transporting, and analytical techniques were undertaken on three duplicate samples taken by the Scripps Institution boat on May 21, 1934, five miles off shore from the Institution at Lat. 32° 55'5W, Long. 117° 21'W. The water temperature at this station was 19.7° C. and the salinity 33.49 0/00. The low activity of the water and the unavoidable delays incident to completing the radon analyses on each specimen in its turn result in a high probable error for the excess radon in the samples analyzed last. In spite of this there are a few conclusions which may be drawn from these data. (Table V.) It seems rather definite that the radium concentration at this station cannot have greatly exceeded 0.5 x 10^{-16} g Ra per cc nor the excess radon have been much more than 1 x 10^{-16} curie per cc. This station, however, is very close, both in position and season, to that from which Devaputra, Thompson, and Utterback examined ten specimens taken at depths of 0 to 600 meters in June 1930 at Lat. 32° 52'W, Long. 117° 21'W. Their results range from 37. to 46. x 10^{-16} g Ra per cc, or more than a hundred times the values obtained in our experiments, and they show no clear variation with depth. In the previous section an explanation for these differences was proposed.

TABLE V.

Scripps Ocean Water Specimens, May 21, 1934.
Lat. 32° 53'5 N., Long. 117° 21' W.

Sample	Depth	Radium in 10^{-16} g Ra per cc	Excess Radon in 10^{-16} curie per cc
8493	Surface	0.2 ± 0.2	0.4 ± 0.3
8494	Surface	0.3 ± 0.3	1.1 ± 0.6
8495	Surface	0.0 ± 0.3	1.8 ± 0.7

A surface specimen (8499) taken June 7, 1934 from the deep end of the Scripps Institution pier (water temperature 20.8° C.) showed 0.4 ± 0.4 x 10^{-16} g Ra per cc and 0.8 ± 0.6 x 10^{-16} curie excess radon per cc, in entire qualitative agreement with the low values found at all the off shore stations.

Through the kindness of Prof. C. L. Utterback, Mr. L. A. Sanderman of the Friday Harbor Oceanographic Laboratories of the University of Washington collected for us four one-liter specimens of surface water July 18, 1934 from off Yellow

Island, in the middle of the San Juan Channel. The station was at Lat. 48° 35′N, Long. 123° 3′W and is essentially the same as that from which Devaputra, Thompson, and Utterback analyzed specimens in the summer of 1930, reporting 47. x 10^{-16} g Ra per cc for surface water. The train trip from Seattle to Berkeley is too lengthy to prevent appreciable decay of excess radon during the shipment of the specimens. Consequently we examined the specimen for radium only, finding 0.6 ± 0.2 x 10^{-16} g Ra per cc, in good agreement with our other results on Pacific waters.

Devaputra, Thompson, and Utterback had also studied seawater specimens from the north Atlantic, approximately 100 miles off shore from Ocean City, Maryland. For these and their Hudson Bay specimens they obtained about ten times the radium concentration of their Pacific samples. Dr. H. B. Bigelow of the Woods Hole Oceanographic Institution generously supplied us with four liters of surface water made up from several stations in the central part of the Gulf of Maine, about 100 miles off shore from Boston. The chlorinity of the mixture was 17.925 0/00. Our radium analyses showed 1.5 ± 0.4 x 10^{-16} g Ra per cc, which is somewhat higher than our Pacific Ocean results, but again is less than one per cent of the concentration reported by Devaputra, Thompson, and Utterback.

IV. DISTRIBUTION OF RADIUM IN BOTTOM SEDIMENTS.

The high radium content of the fine mud associated with the water specimen 8489 (Table II), from a depth of 1,300 meters, and the suggestion from Table II that this is due in part to the precipitation of radium from the overlying water, led to the following experiment on the radium concentration in the coarse- and fine-grained fractions of a typical bottom mud.

With the small Scripps Institution boat and a pipe dredge, about one kilogram of bottom mud was collected at the station of Table IV where the water is only 276 meters deep.* The dredge brought up about one liter of water with the mud, and as this contained some of the finer sediments in suspension, the entire sample was dried at water-bath temperatures.

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* The Pacific Ocean shipping strike had prevented making alterations on the large Scripps Institution boat which would have made it possible to collect a large sample of the mud from the deep station of Table II.

Thus the salt from about a liter of water was in the mud. About an eighth of this dried material was removed and radium measurements, carried out on it by the usual direct fusion furnace technique[11], gave 0.57 ± 0.02 x 10^{-12} g Ra per g.

The remainder of the sample was suspended in distilled water and, after partly settling, filtered through a Berkefeld filter. The wash water (2 liters) contained only 0.9 ± 0.3 x 10^{-16} g Ra per cc; hence no significant amount of radium was leached out of the material. The sediment remaining on the filter was added to the rest of the mud samples. More distilled water was added and the material sieved to obtain fractions one and two (Table VI). The remainder of the sample was suspended in distilled water and further separated by settling as described in Table VI. All the samples were then dried on a water bath, then for several hours in an oven at 110° C. The two liters of wash water from fractions one to six contained 0.7 ± 0.2 x 10^{-16} g Ra per cc, which is probably somewhat less than normal sea water at this station and depth, and the total radium involved is negligible in comparison with the radium found in the solid fractions.

About three grams of each of the fractions were weighed out, heated for three to five hours at about 1,000° C. to break down the carbonates, sealed in glass tubes for a month, and then analyzed for radium by the direct fusion furnace technique.[11] The right-hand column of Table VI shows that all the radium found in the analyses of the bulk sample is exactly accounted for in the analyses of the seven graded fractions. Doubtless fraction three, which makes up 80 per cent of the bottom deposit and is mainly sand, is representative of terrigenous materials washed to this near-shore area by ocean currents and tides. Its low radium content is in entire general accord with the radium content of various terrestrial materials[18, 19] measured with the same apparatus and techniques.

The main concentration of radium is found in those fractions containing the fine material of a few microns diameter. This finding supports the view that the high radium content of deep-sea sediments is mainly due to fine particles which have settled down from the overlying water.

If, as at least one author[20] has suggested, the radium in the ocean were due to radium dissolved out of the bottom sediments, then a concentration gradient similar to that found in section III might be expected. In this case, however, the original source of the radium in the bottom sediments would

Table VI.

Distribution of Radium in Mud Sample 8496 from 276 Meters Depth, Lat. 32° 52′5 N., Long. 117° 16′8 W. after Mechanical Analysis.

Fraction	Description	Wgt. Grams	Fractional Weight	Radium in 10^{-12} g Ra per g	Radium Concentration x Fractional Weight
1	Particles more than 1 mm diameter, mostly shells.	3.7	0.0043	0.18 ± 0.02	0.0008 x 10^{-12}
2	1.0 to 0.5 mm diam.	0.2	0.0002	....	....
3	0.5 to 0.05 mm sand, settled in about 1.5 minutes.	690.	0.80	0.43 ± 0.01	0.340
4	50 to 7 microns, coarse silt, settled in about 30 minutes.	86	0.0996	1.05 ± 0.02	0.105
5	7 to 3 microns, fine silt and coarse clay, settled in 2 to 3 hours.	40	0.0464	1.11 ± 0.02	0.0515
6	3 to 1 microns, clay and colloid, settled in 3 days.	23	0.0266	1.31 ± 0.02	0.0348
7	Less than 1 micron. Colloid. 18 g remained in suspension more than 3 days when water removed by evaporation. 1.4 g obtained by filtration of water used in separating fractions 1 to 6.	19.4	0.0235	1.11 ± 0.03	0.026
TOTALS		862.	1.000		0.56
BULK MATERIAL			1.00	0.57 ± 0.02	

be obscure, and it seems much more likely that the radium in the ocean has its origin in the rocks of the land areas, and is leached out by rain and ground water and carried to the ocean by the rivers.[21] Moreover, if radium were being dissolved from the bottom sediments more rapidly than it is being precipitated, the fine-grained portions of the bottom sediments might be expected to be poorer in radium than the large-grained material. The precipitation mechanism is supported by the observation of the highest radium concentration in the finer fractions of the bottom mud.

V. RADIUM CONTENT OF MARINE LIFE.

The evidence of sections III and IV suggest that radium is being continually precipitated out of the ocean. The mechanisms might be strictly chemical, depending on the dissolved oxygen content of the water and other factors, or they might involve biochemical processes as well. If only ordinary chemical precipitation were present, fraction seven of Table VI would probably have been much more active than the others.

Shelled animals are known to conduct a very efficient calcium-accumulating process, withdrawing this element from the water and carrying it toward the bottom with them when they die.[22] Marine plants are effective in concentrating iodine and potassium, and the marine alga *Fucus vesiculosus* is reported[23] to concentrate barium so that its Ba concentration is several hundred times that (0.02 per cent) of the ocean water in which it lives. A similar process in the case of radium might go far to explain the results of sections III and IV. It is therefore of interest to examine the radium content of various forms of marine life, particularly plants and small animals since these have the greatest surface area per unit volume. A few tests of this type were carried out on kelp and plankton, both of which exhibit radium concentrations of about one hundred times that of the water in which they live.

Samples of kelp and plankton were prepared at the Scripps Institution laboratories and analyzed for radium at Berkeley employing the direct fusion furnace technique.[11] Kelp was found difficult to prepare. An unweighed quantity of fairly dry kelp was heated to between 650° and 700° C. for about seven hours a day for more than a week. In addition to removing the carbon by combustion this technique fused some of the salts, probably of magnesium, and the ash was broken up occasionally. The resulting ash had a radium content of $0.21 \pm 0.02 \times 10^{-12}$ g Ra per g.

Taking the industrially-determined weight ratio of living kelp to dry kelp of ten to one, and assuming that the weight ratio of dry kelp to its ash is as much as ten to one, there still remains a factor of 100 between the radium concentration in living kelp and its ocean water medium.

Further samples were prepared by taking about 50 g of this ash and extracting first the portion soluble in boiling distilled water, then the portion soluble in nitric acid. The original ash was extracted with boiling distilled water until a chloride-free insoluble residue remained. The dissolved salts were then recovered by evaporation of the water, following which they were heated to 500° C. These water-soluble salts had a radium content of $0.09 \pm 0.02 \times 10^{-12}$ g Ra per g.

The insoluble residue was heated with 100 ml of nitric acid and filtered. The filtrate, with 15 ml of hydrochloric acid added, was evaporated to dryness, and the salts incinerated at 650° C. These nitric acid soluble salts contained $0.73 \pm 0.02 \times 10^{-12}$ g Ra per g.

The insoluble residue from these two extractions, after being evaporated to dryness with hydrochloric acid and incinerated at 800°C., weighed 1.2. g, and had a radium concentration of $0.75 \pm 0.06 \times 10^{-12}$ g Ra per g. The significance of these kelp fractionations is not yet obvious. The results are recorded for the benefit of experimenters who may later investigate this problem.

At the time these analyses were being made, the water contained practically no plankton which could be caught in a tow net. A sample of plankton, collected earlier in Mission Bay, California, was therefore analyzed. The sample consisted mainly of small schizopod crustaceans and is not representative of typical oceanic plankton. From 16 grams of dry plankton, 1.40 g of ash were obtained by incineration. Radium analysis of the ash showed that the original dry material had a radium concentration of $0.040 \pm 0.003 \times 10^{-12}$ g Ra per g. Assuming the dry plankton represents only ten per cent of the weight of the living plankton, we see that the living organism contained more than 100 times the radium concentration of typical Pacific Ocean surface water.

Fragmentary as these results are, they do definitely indicate the importance of biochemical processes in all considerations of radium chemistry in the sea. An extended investigation of these questions might bring many interesting matters to light.

VI. DISCUSSION.

These experiments have indicated that sea water is much poorer in radium than the results of earlier workers had suggested. Therefore, accurate analyses require much more refined technique and apparatus than that previously used. A 1,600 cc sample of sea water contains only the order of 10^{-13} g of radium, and less than 10^{-18} g of radon. This radon must be quantitatively removed from the specimen and placed in an ionization chamber, where it will produce only the order of 25 alpha rays per hour. The unavoidable radium content of the metal walls of the chamber produces some 200 alpha rays per hour, while cosmic rays and local gamma rays increase this background ionization even further. Ionization current observations of many hours' duration are therefore required and even at best the statistical fluctuations in the random emission of the alpha rays result in a fairly large probable error.

In every case the probable error r is given for each of the present measurements. From the theory of errors it follows that the probability that the true result lies outside the range $a \pm r$ is exactly one-half, while the chance that the measured value a, differs from the true value by more than $2\ r$ is 0.18, and the chance that a differs from the true value by more than $3\ r$ is only 0.044.

In section III a marked increase in the radium concentration of ocean water with depth is shown. Surface waters in the Pacific Ocean near the United States coast run about 0.2 to 0.3×10^{-16} g Ra per cc, while at a depth of 1,300 meters the water contains about ten times this concentration of radium. It seems probable that this is indicative of a continuous process of settling of radium in the sea, for the radium in bottom sediments is usually highest where the water is quiet and deep, and the finest particles in the bottom mud contain the highest radium concentration. Coarse material washed in from neighboring land areas is poorer in radium. Finally it appears probable that various forms of marine life concentrate radium, die, and settle to the bottom. It should be remarked, however, that in very deep waters the zone of abundant life may represent only a thin surface layer in the whole ocean depth, hence biochemical concentration is probably aided by other mechanisms.

Radium itself has a half-life period of some 1690 years, and it is of great importance, in connection with any studies of the rates of oceanic processes, to know whether radium in the ocean and in deep-sea sediments is in equilibrium with its radioactive parent, uranium. Hernegger and Karlik[24] have recently succeeded in measuring spectroscopically the uranium content of a few specimens of sea water, collected near Sweden, by means of the ultra-violet fluorescence supported by the uranium after it has been chemically concentrated into a small sodium fluoride bead. Their present values range from 0.36 to 2.3 x 10^{-9} g uranium per cc of water. This amount of uranium would support from 1.2 to 8 x 10^{-16} g radium per cc if radioactive equilibrium were present. The radium content of their water specimens has not been measured.

Finally Botset[25] has published radium analyses of connate waters, which are probably derived from ancient seas and are now held stationary in deeply buried rocks. These waters may contain several times the salt content of modern seas, and usually show a low concentration of sulphates. Botset's radium values range between 5 and 19 x 10^{-18} g radium per cc, which seems very high and may be partly due to radium dissolved out of neighboring soft rocks.[26]

Unambiguous answers to many of the oceanographic questions concerning the radioactivity of ocean waters, life, and sediments cannot yet be given because too minute a fraction of the ocean areas has been sampled. However, reliable analytical techniques are now available for extending the range of knowledge in these fields, and the general nature of the results to be expected is beginning to be understood. The radium content of the organic fraction of bottom muds should be accurately studied, because of its important bearing on the mechanism of biochemical precipitation processes.

These analyses were carried out by Evans and Kip at the University of California in the spring and summer of 1934, during the National Research Fellowship tenure of one of us (R.D.E.). The hearty support given by Prof. L. B. Loeb, Dr. T. Wayland Vaughan, and other members of the University staff is gratefully recalled.

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ANCIENT EROSION SURFACE IN THE GALLUP-ZUÑI AREA, NEW MEXICO.

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ABSTRACT.

The surface of the plateau west of the Zuñi Mountains, New Mexico, is an exhumed erosion surface, here called the Zuñi erosion surface, of probable late Tertiary age. It bevels Cretaceous and pre-Cretaceous rocks and is overlain by dissected Tertiary beds containing limestone, marl, tuff, and bentonitic clay, and Pleistocene (?) beds containing land and freshwater mollusca. The abnormally high westward slope of the surface indicates deformation by westward tilting subsequent to the deposition of the overlying Tertiary beds.

INTRODUCTION.

The area lying between the coal town of Gallup and the Indian pueblo of Zuñi is a dissected plateau standing between 7,000 and 7,400 feet above sea level, the surface of which slopes gently westward from the Zuñi Mountains which rise 1,000 to 1,500 feet above it. It is drained by Zuñi River and the Rio Puerco of the West which, together with their tributaries, have cut canyons in it 500 to 700 feet deep. This plateau is underlain by layers of sedimentary rock which, for the most part, appear to be horizontal, but close inspection reveals dips apparent to the naked eye and a survey of the region as a whole shows that strata of several ages crop out at the surface, indicating that the surface of the plateau is controlled by erosion rather than structure. This surface cuts the Cretaceous and pre-Cretaceous beds of the area and parts of it are still covered by Tertiary and Pleistocene(?) deposits (Fig. 1).

No detailed description of this surface has ever been published. Shaler[1] and Sears[2] have prepared maps relative to local coal resources, which take cognizance of its existence. It can be seen on one of Darton's[3] structure sections. Bryan[4] has described it briefly in an unpublished report.

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[1] Shaler, M. K.: "A reconnaissance survey of the western part of the Durango-Gallup coal field of Colorado and New Mexico," U. S. Geol. Surv. Bull. 316, pl. 22, p. 376, 1906.

[2] Sears, Julian D.: "Geology and Coal Resources of the Gallup-Zuñi Basin, New Mexico," U. S. Geol. Surv. Bull. 767, pp. 1-52, map, 1925.

[3] Darton, N. H.: "'Red Beds' and Associated Formations in New Mexico," U. S. Geol. Surv. Bull. 794, p. 153, fig. 59, 1928.

[4] Bryan, Kirk: "Geology of Zuñi Reservoir near Zuñi, New Mexico, and its watertightness as affected by the proposed increase in the height of the dam," pp. 7-9 (unpublished), 1928.

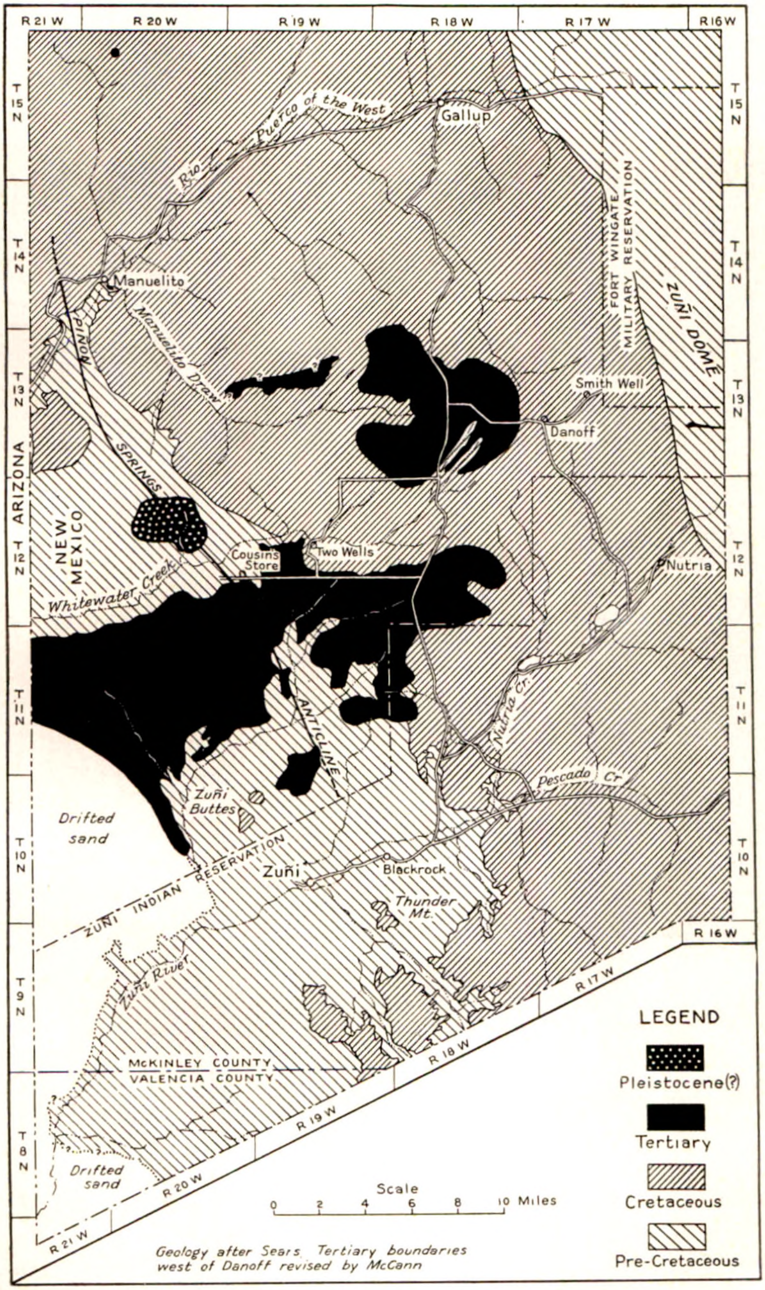

Fig. 1. Generalized geologic map of Gallup-Zuñi area, New Mexico.

A number of factors combine to make the area interesting for those persons concerned with the late Tertiary and early Pleistocene history of Arizona and New Mexico. There has been no apparent deformation here since the deposition of the Tertiary beds save westward tilting and probable minor differential warping. This gives significance to the estimated amount of uplift of the Zuñi Mountains since the deposition of the Tertiary beds, a figure reached by comparing the present high westward slope of the surface with the much lower gradient of the present streams. The presence of limestone, marl, tuff, and bentonitic clay in the Tertiary beds makes possible a tentative correlation with similar beds in adjacent areas and consequent tentative age assignment. The presence of Pleistocene(?) mollusca in certain lake or spring deposits adds materially to the knowledge of local Pleistocene climate, a

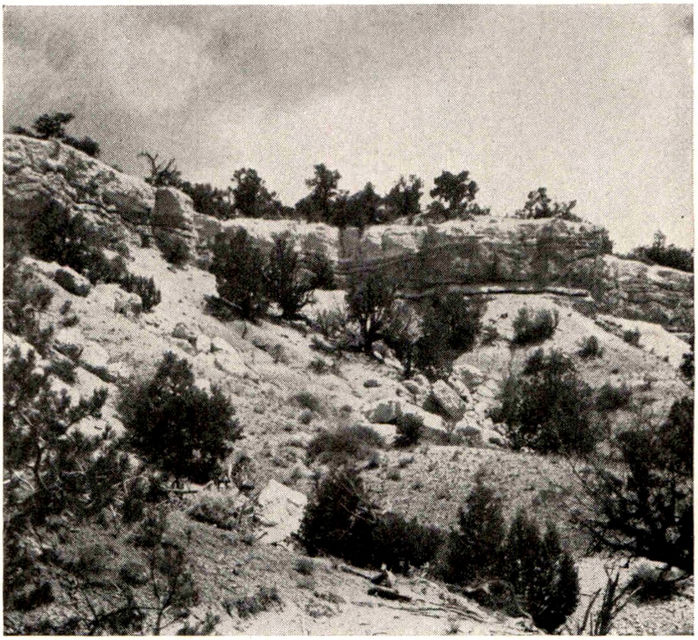

Fig. 2. Tertiary beds at locality A (Fig. 8), showing clay beds overlain by cliff-forming, white tuff and tuffaceous sandstone. Note blocks of white tuff lying on slope in foreground.

matter of general and present interest to anthropologists[5] as well as to geologists.

The Tertiary and Pleistocene(?) deposits of the Gallup-Zuñi area are much less resistant to erosion than the underlying Cretaceous and pre-Cretaceous beds. The streams in the area, by headward erosion, tend to strip these less resistant post-Cretaceous beds completely from the Zuñi erosion surface (Fig. 3) and then dissect the surface itself. Because of this method of attack, the surface is either completely concealed or virtually destroyed save at the margins of the Tertiary and Pleistocene(?) areas (Figs. 1, 8). Here the conditions are especially favorable for examination of buried monadnocks and determination of the slope of the surface since the angular unconformity between post-Cretaceous and the older rocks (which is also the edge of the Zuñi erosion surface) is exposed for considerable distances. The gradient of the surface has been determined by means of points of known elevation (Fig. 8), all of which are located on the unconformity save for that on Thunder Mountain, 7,356 feet, which is on a monadnock above the surface, and that at Nutria, 7,406 feet, which is on the highest Cretaceous outcrop in the vicinity yet below the surface. These and other elevations not shown on Fig. 8 were measured in several ways. Wherever practical a level line was run by means of plane table and telescopic alidade from a bench mark established by the United States Coast and Geodetic Survey or the United States Geological Survey. In other cases, a barometer traverse was run from these same bench marks and checked by return traverse, and if possible rechecked with a Brunton compass.

STRATIGRAPHY OF THE PRE-TERTIARY ROCKS.

The stratigraphy and structure of the pre-Tertiary rocks of the Gallup-Zuñi area have been so adequately described by Sears[6] and Darton[7] that only an outline seems necessary here. The following account is drawn largely from these two sources.

The core of the Zuñi Mountains is composed of a pre-Cambrian crystalline complex, exposed only in the central part of the mountains, on which lie approximately 6,000 feet of sedimentary rocks. The oldest of these sedimentary rocks consist of beds of sandstone and limestone, about 175 feet thick, which belong to the Chupadera formation of Permian age. Above these beds lie two great bodies of Triassic shale, the Moenkopi and Chinle formations, separated from each other by the relatively thin Shinarump conglomerate. The maximum thickness of Triassic rock is approximately 1,880 feet.

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[5] Eiseley, Loren C.: "Index mollusca and their bearing on certain problems of prehistory: a critique," Philadelphia Anthropological Society, Twenty-fifth Anniversary Studies, pp. 77-93, 1937.

[6] Op. cit.

[7] Op. cit.

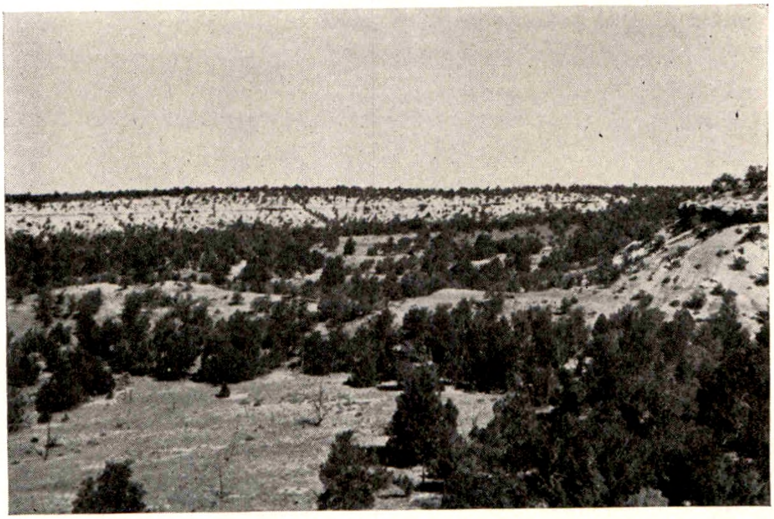

Fig. 3. View near locality B (Fig. 8), showing stripped erosion surface in foreground, exposed by waters of Manuelito Draw, a tributary of the Rio Puerco of the West.

The Jurassic is represented by the Wingate sandstone, and by rocks previously considered as correlatives of the Todilto formation, and the Navajo sandstone. The local "Todilto" and the "Navajo" are now considered part of the Morrison formation[8] of probable Jurassic age. The "Todilto" includes limestone and some gypsum. The Wingate and "Navajo" sandstones are massive, cross-bedded, and pink or red in color. These beds have a maximum thickness of 1,025 feet.

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[8] Baker, A. A., Dane, C. H., and Reeside, J. B. Jr.: "Correlation of the Jurassic Formations of parts of Utah, Arizona, New Mexico, and Colorado," U. S. Geol. Surv. Prof. Paper 183, pp. 17, 63, 1936.

On the geologic map (Fig. 1), all the beds older than the upper Cretaceous have been shown under one symbol as "pre-Cretaceous."

The upper Cretaceous beds have a maximum thickness of 3,125 feet and consist of massive, buff sandstones and dark shales which overlie unconformably all the older beds. These include the Dakota sandstone, the Mancos shale, and the Mesa Verde sandstone.

STRUCTURE OF THE PRE-TERTIARY ROCKS.

After the deposition of the upper Cretaceous beds, the Zuñi Mountains were arched up in a broad dome and the sedimentary rocks immediately to the west were warped down to form a broad, shallow syncline or structural basin (Fig. 1) with minor folds. Both dome and basin trend northwestward and the basin plunges gently in the same direction.

THE TERTIARY DEPOSITS.

The Tertiary deposits of the Gallup-Zuñi area consist of loosely consolidated alluvial and lacustrine beds of high tuffaceous content which vary widely in texture and lithology. Locally they appear to be horizontal, but regional relationships reveal a slight dip to the west. Sears[9] dismisses these beds briefly as "unconsolidated reddish sand and clay, some soft white sandstone, light-gray clay shale, and gravel, lying unconformably upon the older formations." More detailed investigation indicates that there is, in addition, limestone, marl, white tuff, sandstone with a considerable content of tuff, and bentonite or related clay mineral. A small area (Fig. 1) of alluvium and black silt, which was included by Sears in the Tertiary, is here considered to be Pleistocene(?).

The beds west of Danoff (A-E, Fig. 8) range in thickness from 50 to 150 feet. At A and B, they are composed of variegated clays capped by a layer of scarp-forming white tuff (Fig. 2) in close association with thin, brown to red sandstones which are also scarp-forming and tuffaceous. The series at A includes three thin layers of bentonitic clay below the white tuff and above it a somewhat thicker layer of gray tuff containing glass fragments so angular and quartz-free as to suggest an ash-shower not reworked by water. The index of refraction of this glass is 1.502 which indicates[10] a silica content of 70 per cent and therefore a glass of rhyolitic composition. The bentonitic clay is considered to be decomposed volcanic ash and the presence of fresh ash above decomposed ash would seem to indicate a lowering of the water-table during the deposition of these beds.

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[9] Op. cit., p. 18.

The beds at C resemble those at A and B save that the clay has a slightly higher percentage of sand and the bentonitic clays are absent, but the beds at D and E are quite different. The white tuff disappears, there is a notable increase in the percentage of sand and limy sandstone, and a thin, resistant limestone appears, indicating the presence of a small, temporary lake. There is a thick layer of gray bentonitic clay at E.

The white tuff, in association with brown, nodular, resistant, tuffaceous sandstones, which may be found both above and below the white tuff, seems to hold up the present surface of the plateau here save at D and E. These beds may be seen at numerous points along the Gallup-Zuñi Road, the Danoff Road, the Two Wells (Correction Line) Road and the trails which lead off from them, for the tuff and sandstone are used for road metal in the vicinity and shallow pits have been opened for this purpose along the roads named. Apparently, these beds, on account of the porosity of the white tuff and the hardness of the brown sandstone, resist erosion until the underlying clays are worn away at the bordering cliffs, and the white tuff, thus undermined, breaks off in great blocks (Fig. 2). In this manner, headward-working tributaries of Whitewater Creek and the Rio Puerco of the West are slowly stripping off the Tertiary cover (Fig. 3). Tributaries of the Zuñi River perform a similar function in a less spectacular manner in the Tertiary area south of Cousins Store.

The Tertiary deposits south of Cousins Store (Fig. 1) have the greatest areal extent but not the maximum thickness for the Gallup-Zuñi area. Here the maximum thickness is 135 feet (Fig. 8, J). There is no white tuff, but a white bentonitic clay, one to two feet thick, may be found at G and H (Fig. 8). A notable percentage of gravel is present at G and J (Fig. 8). The pebbles which are found in the gravel are largely derived from the Zuñi Mountains to the east. There are a few granite pebbles which must have come from the core of the mountain and many pebbles of quartz, quartzite, jasper, flint and red chalcedony which are probably derived from conglomeratic zones in the steeply-dipping pre-Cretaceous beds near the base of the mountain. The quartzitic pebbles are well rounded and have shapes obviously related to some pre-Tertiary cycle of erosion. They also show small faults which were acquired in the deformation of their parent beds, presumably during the pre-Tertiary uplift of the Zuñi Mountains. The percentage of sand is much greater and the percentage of clay much less than in the area west of Danoff.

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[10] Grout, Frank F.: "Petrography and Petrology," p. 114, 1932.

The angular unconformity separating these beds from the underlying Cretaceous and pre-Cretaceous is apparent only in the vicinity of the Piñon Springs anticline (Fig. 1) where they overlap the uparched Wingate sandstone, decreasing in thickness from 75 to 20 feet in the space of 200 yards. Its presence is further indicated by the succession of rocks from Cretaceous to pre-Cretaceous, from east to west, each bed neatly beveled and overlain by the Tertiary cover (Fig. 1). The overlap just described indicates an initial irregularity in the Zuñi erosion surface. The measured sections produce additional evidence of irregularity. At G (Fig. 8), 35 feet of sand and limy sandstone separate the white bentonitic clay from the underlying Cretaceous shale, while at H (Fig. 8), two feet of yellow clay separate this bed from underlying Cretaceous sandstone.

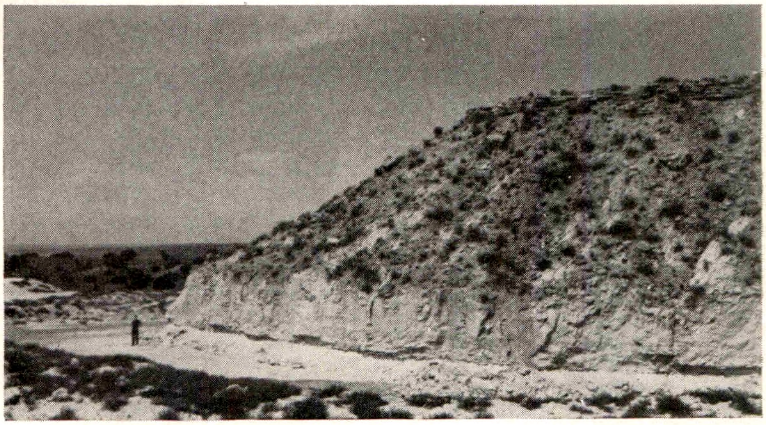

Fig. 4. Tertiary beds at road metal quarry, about 5 miles southeast of Sanders, Arizona. Note bed of white bentonitic clay at base of scarp.

The Tertiary sediments continue westward across the New Mexico-Arizona line, and southwestward they grade into drifted sand. This sand has been reworked in post-Tertiary time, but part of it may represent the top of the Tertiary cover at this point. Neither continuation was studied in detail. A reconnaissance trip into Arizona indicates that the Tertiary beds continue westward for at least 50 miles. One section, seen at a road-metal quarry (Fig. 4) about five miles southeast of Sanders, Arizona, includes a bed of white bentonitic clay, two to three feet thick, which is the source of the road metal. It resembles the white bentonitic clay found at G and H (Fig. 8) and may be the white tuff decomposed. Another section (Fig. 5) observed at Beacon Light Ridge, on the Sanders-Witch Wells Road (State Highway 81), about 14 miles south of Sanders, shows approximately 300 feet of fine, buff sand carrying lenses of resistant, concretionary, limy, gray to buff sandstone and thin beds of brown clay, with a layer of gray to white marl, two to six feet thick, near the top of the series. This marl is similar to one found at I (Fig. 8).

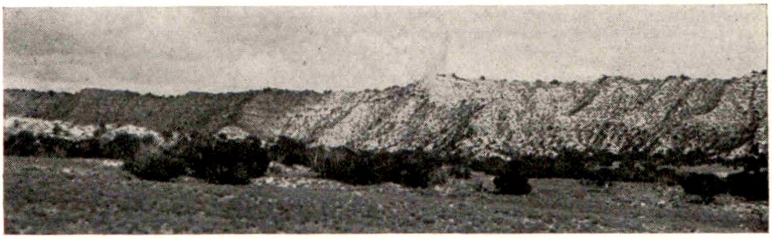

Fig. 5. Tertiary beds exposed in Beacon Light Ridge, about 14 miles south of Sanders, Arizona.

THE PLEISTOCENE(?) DEPOSITS.

The Pleistocene(?) beds (Fig. 8, F) west of Two Wells differ in thickness and lithology from the Tertiary beds, and contain land and freshwater mollusca. They are relatively thin, having a maximum thickness of 50 feet. At the base is a coarse, limy conglomerate (Fig. 6), five to 20 feet thick, showing marked cross-bedding and channeling. The coarser material is a crudely sorted mass of rock fragments ranging in size from sand to slabs of sandstone three feet across. It contains well rounded pebbles of white marl, clearly derived from Tertiary beds, numerous fragments from the underlying Navajo-Wingate sandstone, and minor amounts of quartz, quartzite, jasper, flint and red chalcedony. Above the conglomerate lies a thin, soft, brown sandstone which also contains pebbles of red chalcedony. On top of the sandstone rests a layer of black to gray, limy silt and clay, two to three feet thick, containing two species of land gastropods and several species of freshwater mollusca. This layer dips downstream at about the same rate as the present stream gradient and also exhibits slight irregularities in dip (Fig. 7). This seems to be due to irregularities in the surface of the underlying conglomerate and sandstone on which it was laid down. Above the black silt is six to ten feet of loose, brown silt which may have been deposited by water in a swamp or distributed by the wind over a grassy area.

It seems likely that the molluscan layer represents a spring rather than a lake deposit. There are several springs existing in this part of the Zuñi plateau at the present time. The arroyo along whose banks this layer is exposed is a spring arroyo in whose bed is a black muck, masked by a thin veneer of sand, very like the shell layer.

The mollusca found in the shell layer include the following forms, kindly identified by Mr. William J. Clench of the Harvard Museum of Comparative Zoology:

Freshwater gastropoda.

Aplexa hypnorum Linn.
Physa virginea Gould.
Lymnaea (*Galba*) *humilis modicella* (Say).
Lymnaea (*Galba*) *palustris* (Mull).
Succinea retusa Lea.

Land gastropoda.

Vertigo ovata Say.
Gyraulus parvus Say.

Pelecypoda.

Sphaerium sp.

The vertical range of these mollusca is so great (pre-Tertiary to present) that these specimens can in no sense be regarded as index fossils and indicative of precise age. They do, however, seem to indicate a somewhat colder, more humid climate than exists on the Zuñi plateau today and on that account may be Pleistocene. Mr. Clench regards this assemblage as essentially a cold-water fauna and characteristic of relatively clear, shallow waters of the present north temperate and sub-arctic zones. The pupillid, *Vertigo ovata* Say, is especially hardy and while it ranges as far south as northern Mexico, it is also found as far north as southern Alaska. Still, this evidence must be regarded as inconclusive inasmuch as the present range in temperature on the Zuñi Plateau may be great and the seasonal rainfall considerable. The mean winter temperature is about 30 degrees Fahrenheit, the reservoir at Blackrock freezes nearly every winter and heavy snows on the plateau are not uncommon. The average annual rainfall is 14 inches. The Zuñi Indians irrigate their fields along the Zuñi River, yet there is sufficient moisture on the plateau during the summer months to enable the Navajos to produce a successful bean crop by dry-farming methods. The presence of *Aplexa hypnorum* Linn furnishes the most satisfactory, positive evidence for a colder, more humid climate at the time this layer was deposited. This gastropod is not known to live today south of Utah and Colorado but is found living in considerable quantities in northeastern United States, north of the southermost boundary of the Wisconsin ice.

The record of Pleistocene events in the areas covered by Tertiary deposits is largely buried beneath a cover of fine detritus which is partly alluvial and partly wind blown. No fossils were found there nor are there any changes in lithology which might bear on this point with the possible exception of the presence of quartzitic gravel (Fig. 8, G, J), some of which may be Pleistocene. It seems likely that the sand cover west of the pueblo of Zuñi (Fig. 1) represents the top of the Tertiary at that point reworked by the wind during Pleistocene and Recent time. Along Zuñi River, much sand is at present being spread out by the river and its tributaries and transported by the wind a short distance from their floodplains. When the river grade was at the level of some of the high terraces, this process may have been much more effective and may account for some of the windblown sand to the north. There is a small amount of windblown sand in the Tertiary area west of Danoff (Fig. 1), in T.13 N, R.18 W, Section 9. In the Tertiary area south of Cousins Store (Fig. 1), the presence of a few windcut stones and low hills which have the appearance of old dunes indicates the reworking of the top of the Tertiary series there by the wind. Much of this sand was moved in the past, but there is a small area in T.12 N, R.19 W where sand is still being moved by the wind at the present time. This suggests that the top of the Tertiary cover throughout the Gallup-Zuñi area may have been reworked by the wind in Pleistocene and Recent time.

ZUÑI EROSION SURFACE.

The period of uplift, during which the Zuñi Mountains were domed and the Cretaceous and pre-Cretaceous rocks of the Gallup-Zuñi area warped down, was followed by a period of quiescence when an erosion surface, here called the Zuñi erosion surface, was formed, sloping gently westward from the Zuñi Mountains which then rose as residuals 500 to 1,000 feet above it. The considerable extent of the surface, as indicated by Fig. 8, presupposes that the period of quiescence was relatively long. The contours of Fig. 8 are carried from the immediate areas of the Tertiary beds by extension over the surface of the plateau according to the best available topographic information. The low relief found wherever the surface is both exposed and preserved, as on the margins of the remnants of Tertiary beds (Fig. 3), suggests that it was a smooth and well-developed erosion surface. It seems likely that both rill-wash and the lateral planation of streams flowing westward from the Zuñi Mountains played important parts in the development of the surface, but the absence of the surface in the key area at the immediate base of the Zuñi Mountains makes their relative importance a moot question. Irregularities, both in detail and in the trough-like basin in the central portion of Fig. 8, are characteristic of even a well-developed erosion surface and do not necessarily indicate warping. However, the difference between the present high slope and the probable low initial slope of the surface furnishes strong evidence of westward warping.

It seems likely that the original slope of the Zuñi erosion surface westward from the residual Zuñi Mountains was low, because the bulk of the Tertiary deposits which still partly mantle it have a fine texture. Also the limestone and marl imply that temporary lakes of considerable extent were present. Such lakes could exist only on a surface of low gradient.

The present westward slope of the surface is relatively high.

Where the elevations have been determined (Fig. 8), its inclination is about 30 feet to the mile. Where the surface crosses into Arizona, it continues to slope westward at about the same rate. If the Tertiary beds in the vicinity of Sanders, Arizona, are the same age as those of the Gallup-Zuñi area, then the surface at that place has dropped to about 6,000 feet above sea level.

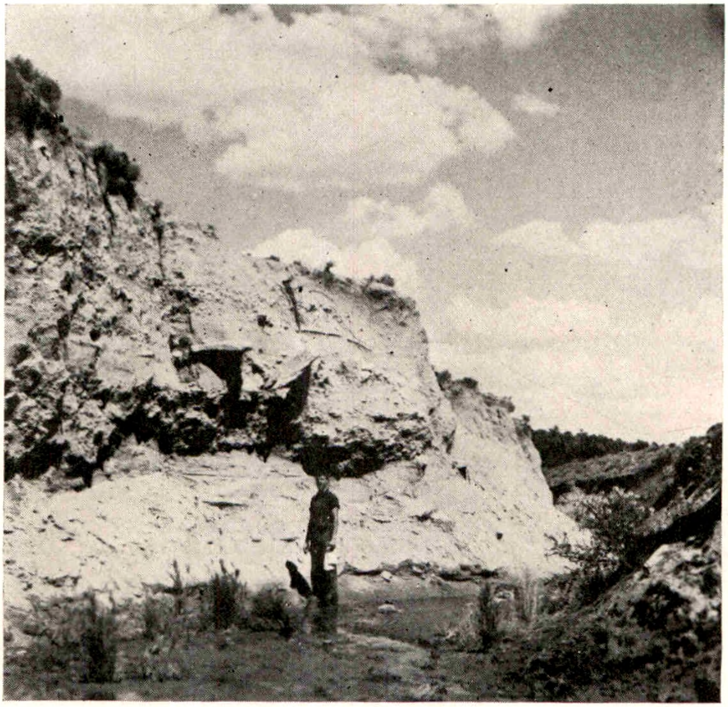

Fig. 6. Coarse conglomerate comprising basal member of Pleistocene(?) series at locality F (Fig. 8).

This is 2,000 feet in 50 miles from the 8,000-foot contour (Fig. 8) to Sanders, or a slope of 40 feet to the mile. From C (Fig. 8) to Sanders, the distance is 40 miles, the difference in elevation 1,150 feet, and the slope 29 feet to the mile. Even if the steepened part of the surface just west of the base of the Zuñi Mountains (Fig. 8) is excluded and the lower gradient of the main part of the surface is considered, the slope is still too high for the type of stream that must be postulated as the depositing agent for the clay and fine sand of the Tertiary beds. The gradient of the Santa Fe railroad tracks between Gallup and Sanders is about 16 feet to the mile and since the tracks are laid on the floodplain of the Rio Puerco of the West, the present gradient of this stream must approximate this figure. The gradient of Zuñi River in the vicinity of the pueblo of Zuñi is approximately 17 feet to the mile. Since the Tertiary deposits resting on the Zuñi erosion surface are, on the whole, finer than those being laid down at present by these two streams, it seems probable that the original slope of the surface was less than 16 feet to the mile. Detailed investigation by the Middle Rio Grande Conservancy along the Rio Puerco of the East shows that its gradient is about 12 feet to the mile in the first 67 miles of its course, from its mouth to the abandoned village of San Ygnacio, where the stream is graded and unbroken by hard-rock ledges. Assuming that the climate of the late Tertiary was similar to that of the present, an initial westward slope of 12 feet to the mile seems not unreasonable. If, however, the late Tertiary climate were more humid, as seems likely, the gradient of such an erosion surface and the streams on it would be even less.

If the original slope of the surface were 12 feet to the mile, the Zuñi Mountains must have been uplifted at least 700 feet since the surface was formed. The probably lower original slope and the steepening of the contours (Fig. 8) east of Danoff and south of the pueblo of Zuñi indicate that the amount of uplift may have been much greater and of sufficient magnitude to have an important bearing on the whole regional structure.

Thus far the westward downwarping has been assumed to be of equal intensity throughout the area. This need not necessarily be true. The bowing of the contours (Fig. 8) near the northern boundary of the Zuñi Indian Reservation indicates that the movement may have been of unequal intensity and greater there than to the north and south. However, the overlapping of Tertiary beds on pre-Cretaceous,[11] local differences in the thickness of Tertiary beds below a key horizon,[11] and the probable existence of Thunder Mountain (Fig. 8) and Zuñi Buttes as monadnocks above the surface indicate initial irregularity, and this basin-like shape may be original and due to erosion rather than secondary and induced by deformation. It seems likely that these factors combined to produce this depression.

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[11] Supra, p. 266.

AGE OF THE ZUÑI EROSION SURFACE.

The Zuñi erosion surface must be younger than the youngest beds it cuts, which are Cretaceous, and older than the oldest beds resting upon it, which are here regarded as middle or upper Pliocene. In the absence of fossil content, the age determination of these beds must be based on their physical characteristics and can at best be only approximate. If these beds are middle or upper Pliocene, the erosion surface on which they rest is probably early or middle Pliocene, or possibly late Miocene.

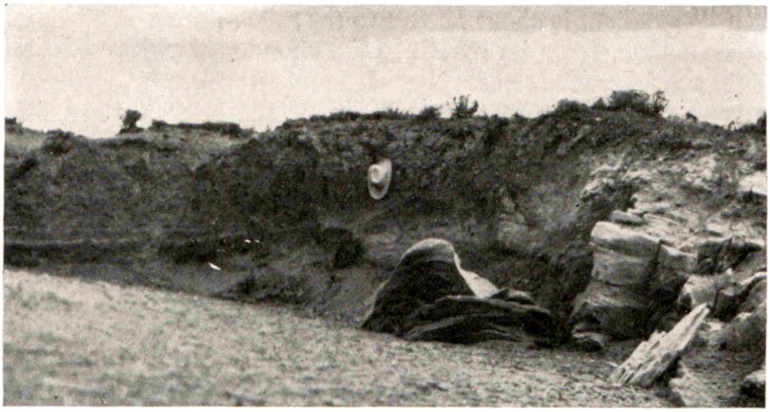

Fig. 7. Pleistocene(?) beds, locally irregular, resting against the upturned edges of the Wingate sandstone. Hat shows horizon of molluscan shells.

The Tertiary series in the Gallup-Zuñi area contains a well-defined and easily recognizable white tuff and associated brown to red sandstones, marl, and bentonitic clay, in addition to some limestone and much sand and clay.

Such a series has sometimes been regarded as early Tertiary in age. Dutton[12] considered a somewhat similar series in the

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[12] Dutton, C. E.: "Mt. Taylor and the Zuñi Plateau," U. S. Geol. Surv. Sixth Ann. Rept., p. 140, 1885.

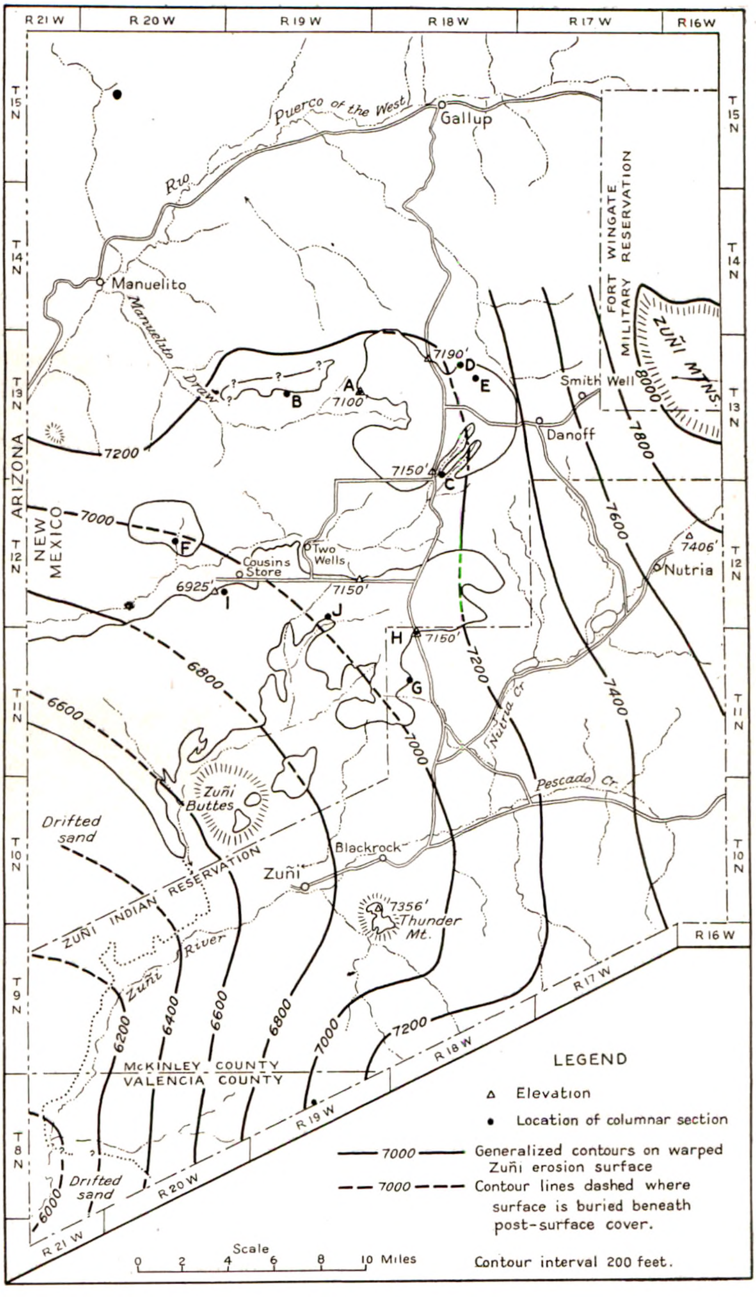

Fig. 8. Contour map of Zuñi erosion surface in Gallup-Zuñi area, New Mexico.

Chuska Mountains to the north as being Eocene, and Shaler[13] thought the same beds Eocene or post-Eocene. Gregory[14] likewise assigned the beds in the Chuska Mountains to the Eocene on the basis of lithology and stratigraphic position, but refused to date the series of sandstones, shales, marls and tuffs in the Hopi Buttes region to the West other than to call it Tertiary.

Recent information indicates that the beds in the Hopi Buttes region are younger than Eocene, and the same may be true of similar beds in neighboring regions, including those in the Gallup-Zuñi area. Reagan[15] collected freshwater mollusca from beds near the Hopi Buttes, identified them as Unio, *Planorbis trivolvis* Say, *Limnaea stagnalis appressa* Say, and referred them to the Pleistocene or Recent. Childs Frick[16] is reported to have assigned to the Pliocene a species of huge camel which he collected there from related beds. Howel Williams[17] collected vertebrates from the same beds which yielded Reagan's mollusca and these he considers of middle or upper Pliocene age. Obviously the matter has not been finally settled, but the evidence seems to indicate that the beds at the Hopi Buttes are middle or upper Pliocene and if the similar beds in the Gallup-Zuñi area are of the same age, as seems likely, the Zuñi erosion surface on which they rest is probably early or middle Pliocene, though possibly late Miocene.

TERTIARY AND EARLY(?) PLEISTOCENE HISTORY.

So far as the record in the Gallup-Zuñi area reveals Tertiary history, the earliest event recorded is the formation of the Zuñi erosion surface. Since this surface appears to have been relatively well-developed, and the Zuñi Mountains were reduced to a narrow ridge largely eroded on the granite core and not over 1,000 feet above the surface at its west base, the cutting probably occupied all of early Tertiary time through latest Miocene or, more probably, early Pliocene. This was followed by differential movement of slight intensity when fine sediments were laid down on the surface. The white tuff contains very little quartz and has not been much reworked, suggesting at least one local ash shower of enough magnitude to overload the streams in the vicinity. Too little is known of the petrology of these Tertiary deposits to warrant a comparison of the relative importance of overloading of streams and downwarping of the area in accounting for their existence. However, their fine texture, the presence of some limestone and marl, and the high proportion of clay, silt and sand indicate that they were deposited on floodplains or in great alluvial fans through which springs occasionally broke to form swamps or small, shallow lakes.

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[13] Op. cit., p. 378.

[14] Gregory, H. E.: "Geology of the Navajo Country," U. S. Geol. Surv. Prof. Paper 93, pp. 79-82, 1917.

[15] Reagan, A. B.: "The Tertiary-Pleistocene of the Navajo country," Kansas Acad. Sci. Tr., Vol. 35, p. 258, 1932.

[16] Williams, Howel: Pliocene Volcanoes of the Navajo-Hopi Country," Bull. Geol. Soc. Am., Vol. 47, p. 130, 1936.

[17] Williams, Howel: op. cit.

A period of uplift and warping, probably at the end of Pliocene time, followed during which large portions of the Pliocene beds were partially stripped off, especially between the present Tertiary areas and the residual ridge of the Zuñi Dome (Fig. 1), and including the locality west of Two Wells, now covered with Pleistocene(?) deposits. Following this movement, the heavy conglomerate containing pebbles of white marl and the other Pleistocene(?) beds were deposited on the stripped surface.

Zuñi River and the Rio Puerco of the West are now flowing 600 to 700 feet below the level of the Zuñi erosion surface. This down-cutting might conceivably be related solely to a continued period of gentle warping. However, the existence of well-developed terraces along Zuñi River[18] indicates that the warping was interrupted by several periods of standstill.

CORRELATION OF ZUÑI EROSION SURFACE WITH NEIGHBORING SURFACES.

Major Tertiary erosion surfaces have been described from various parts of the Colorado Plateau Province. It seems quite possible that all of them, including the Zuñi erosion surface, were formed at approximately the same time. Dutton[19] described one from the Grand Canyon district which he considered Miocene. Huntington and Goldthwait[20] have described a surface from the boundary between the High Plateau

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[18] Bryan, Kirk: op. cit.

[19] Dutton, C. E.: "Tertiary History of the Grand Canyon District," U. S. Geol. Surv. Monograph II, pp. 206-230, 1882.

[20] Huntington, Ellsworth, and Goldthwait, James W.: "The Hurricane Fault in the Toquerville District, Utah," Bull. Mus. Comp. Zool. Harvard Coll., Vol. 42, Geol. Survey, Vol. 6, No. 1, pp. 226-245, 1903.

Province and the Basin and Range Province, to which they have given the place name "Mojave peneplain" but assigned it to no particular epoch. Robinson[21] considered a number of remnants in the Plateau Province, including one in the Mt. Taylor region. He believed them all part of one surface which probably was not complete before late Pliocene time. Dutton and Johnson also have considered the surface underlying the lavas of Mt. Taylor. Dutton[22] thought it quite ancient, referring the lavas which cover it to early Miocene time. Johnson[23] described the surface briefly, but appended no epoch name. Bryan and McCann[24] think this surface relatively young, probably the Ortiz of Bryan's classification, and part of the surface which bevels Santa Fe (late Miocene or early Pliocene) beds in the Ceja del Rio Puerco which lies just within the Basin and Range Province.

ACKNOWLEDGMENTS.

Without the encouragement and advice of Prof. Kirk Bryan, this work would have been neither undertaken nor completed. The intimate knowledge of Mr. Edward Houghton of Two Wells concerning trails and the land net in the Gallup-Zuñi area saved weeks of otherwise necessary field work in connection with the mapping. Mr. Gilbert Corwin of Dayton gave able assistance in the field. Mr. Edward Schmitz prepared the drawings for publication.

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[21] Robinson, H. H.: "The Tertiary Peneplain of the Plateau District, and Adjacent Country, in Arizona and New Mexico," This Journal, Vol. 24, pp. 109-112, 1907.

[22] Dutton, C. E.: "Mt. Taylor and the Zuñi Plateau," op. cit., pp. 177-178.

[23] Johnson, D. W.: "Volcanic Necks of the Mt. Taylor Region, New Mexico," Bull. Geol. Soc. Am., Vol. 18, pp. 307-309, 1907.

[24] Bryan, Kirk, and McCann, Franklin T.: "The Ceja del Rio Puerco: a border feature of the basin and Range Province in New Mexico," Jour. Geol. XLVI, p. 11, 1938.

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WYOMING EOCENE FISHES IN THE MARSH COLLECTION.

MALCOLM RUTHERFORD THORPE.

ABSTRACT.

Wyoming fishes of Eocene age are well represented in the Yale Marsh Collection. Brief descriptions are given of specimens of *Diplomystus, Knightia, Phareodus, Priscacara, Cocherellites,* and *Mioplosus.* A new species of *Phareodus* is described and figured, and keys to the species of the above genera are given.

The large and varied collection of fossil fishes in the Yale Peabody Museum has been but partially studied and catalogued. This collection, containing some types, was assembled chiefly under the direction of Professor Marsh.

The present paper considers some of the fishes of the Middle Eocene Green River formation collected for Professor Marsh by A. Schoomaker in the Bear Lake Valley and southward to Evanston, western Wyoming. They were entombed in the thin-bedded, calcareous, cream-colored shales.

The Green River basin seems to have covered a territory of at least 350 miles north and south and 150 miles east and west. The basin was presumably occupied by shallow lakes, ponds, and marshes, lying near sea level and connected with the sea during a part of its existence, which is estimated to have extended over a period of about eight million years. Some of the species of fishes were unmistakably marine, although probably they became adapted to a fresh-water habitat.

Brown[1] has determined that "the climatic conditions of the southeastern Gulf States plus those of parts of the Great Valley of California would, * * * roughly approximate those of the Green River Lake area." The vegetation surely indicates a warm, temperate region at that time, while the fauna, consisting in part of crocodiles, camels, and a great variety of winged insects and birds on shore, and fishes, molluscs, crustaceans, and so forth in the waters, also points to this climatic condition.

Study of a large number of specimens has added considerably to our previous knowledge of these forms, and a probable new species is herein described.

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[1] Brown, R. W.: Additions to the flora of the Green River formation. U. S. G. S., Prof. Paper 154-J, p. 281, 1929.

SYSTEMATIC DESCRIPTION.

CLUPEIDÆ BONAPARTE.

Diplomystus Cope. Type *D. denatus* Cope.

That the herring stock is of ancient lineage is shown by the genus *Diplomystus* which has been known from Cretaceous time to the present. Its remains have been found in the marine upper Cretaceous of southern Europe, Syria, and Brazil, while representatives of the same genus have been collected in fresh-water Tertiary deposits of North and South America, Africa, and the Isle of Wight. At present *Diplomystus,* or a close ally, still lives in the rivers of Australia and Chile.

The modern herrings are littoral in habitat but do ascend rivers and become fairly easily acclimatized to fresh-water conditions. Although the Green River lakes were fresh in the later stages, yet we know that the basin was connected with the sea at some time during its existence. Perhaps originally these herrings migrated up the streams into the fresher water to spawn and gradually the stock became accustomed to the changed habitat, developing certain acquired characters which differentiated them from the true *Clupea.*

Generic characters: Dorsal and ventral scutes; dorsal scutes transverse, with finely denticulated posterior borders and a prominent median tooth; single series of teeth on dentary, premaxillary, and maxillary bones; lower jaw prominent and cleft of the mouth very oblique; maximum body depth about midway between skull and dorsal fin; ventral outline and post-nuchal region prominent; scales small, 60+; caudal vertebræ 23-25; total number of vertebræ 39-42 (in African and South American forms about 30); dorsal fin, 8-11 rays, originating in front of anal; anal fin, 35-44 rays; pelvic fin small and well in advance of dorsal; pectoral fin extended posteriorly beyond origin of pelvic fin. Total length 79-513 mm.

Key to Species.

D. dentatus Cope: Large and deep-bodied; 365-513 mm. in length and 118-152 mm. in depth. Ratio 2.3-2.6.

D. analis Cope. (*D. theta* Cope): Medium-sized, more fusiform than either of the other species; 79-250 mm. in length and 22-71 mm. in depth; average ratio 2.7-2.9.

D. pectorosus Cope: Small, deep-bodied; 80-103 mm. in length and 25-33 mm. in depth. Ratio 2.4-2.7, rarely 2.8.

Representatives of all of these species have been collected at Bear Lake Valley, Evanston, Fossil, and Twin Creek.

Diplomystus dentatus Cope.

Specific characters: This, the largest species, is the type of the genus. Dorsal fin, 13 rays; pectoral fin, 9 rays; anal fin, 35-39 rays. Abdominal vertebræ, 18-20; caudal, 21-22. Ratio of maximum depth to total length, 3.3; total length, less caudals, 3.33 times that of the head.

There are three excellent examples of this species in the collection. Each has 35 dorsal scutes. That the four species of *Diplomystus, D. analis, dentatus, pectorosus,* and *theta,* are difficultly separable was pointed out by Eastman years ago, and in 1901 Woodward considered the other three synonymous with *D. dentatus.* Based on a careful study of this series, the major distinction is apparently a difference in size. *D. dentatus* and *D. pectorosus,* the largest and smallest species respectively, are slightly deeper-bodied than *D. analis,* but the fin ray and vertebral formulæ apparently do not afford any absolutely distinctive characters.

Cat. No. 3082 is the deepest-bodied of the Peabody Museum specimens, with a depth of 145 mm. and a length of 334 mm., without the caudal fin, giving a ratio of 2.3. There are 19 abdominal and 21 caudal vertebræ, and 13 dorsal, 9 pectoral, and 39 anal fin rays. It was collected just north of Evanston.

Cat. No. 1434 is more fusiform, approaching the lower ratio limit of *D. analis,* with a ratio of 2.6. The total length is 435 mm., or 330 mm. without the caudal fin, and the depth is 121 mm. There are 13 dorsal and 38 anal fin rays, and the same number of vertebræ as above. The specimen is from the Bear Lake Valley.

Cat. No. 1541 (Fig. 1) is the largest example of this species of which I have knowledge. It is very well preserved, except for the pelvic fin which is very small and so obscured in these specimens that no accurate determination can be made of the number of rays. The total length is 513 mm. (20¼ inches) or 387 mm. without the caudal fins. The depth is 152 mm., and the length of skull is 117 mm. The vertebral column has been lengthened to 20 abdominal and 22 caudal vertebræ. There are 13 dorsal and 29 anal rays. The ratio is 2.5, thus being nearly intermediate in bodily proportions to the other two specimens above noted. It was collected by L. Travis in 1890 at Fossil.

Diplomystus analis Cope.

Specific characters: Dorsal fin, 11 rays; pectoral, 11-12 rays; pelvic, 7 rays; anal, 40-41 rays. Abdominal vertebræ, 17-18; caudal, 23-24. Ratio of maximum depth to total length, 3.3-3.7; total length less caudals, 3.33-3.75 times that of the head, which is but slightly less than the maximum depth of the body.

There are more than 38 examples of this species in the collection, of which 26 were collected in Bear Lake Valley and the remainder near Evanston. The average ratio of depth to length, minus the caudal fin, varies between 2.7 and 2.9. Several specimens show 29-30 dorsal scutes between the skull and the first dorsal ray, 25-26 ventral scutes between the skull and pelvic fins, and 7 between the latter and the anal fin.

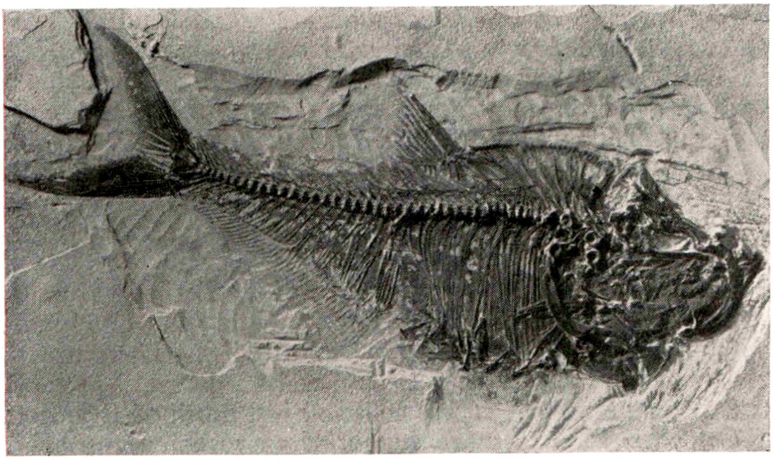

Fig. 1. *Diplomystus denatus* Cope. Cat. No. 1541 Y. P. M. 1/5 nat. size.

The largest specimen in this collection, and the largest so far described, Cat. No. 1927 (Fig. 2), was found at a point just north of Evanston. It measures 250 mm. in total length, or 199 mm. without the caudal fins. Its maximum depth is 71 mm., giving it a ratio of 3.5 on the total length and 2.8 on the lesser dimension. It shows all the specific characters of the smaller forms. Cat. No. 2996 is a typical example of this species from Bear Lake Valley.

There are three unusually deep-bodied specimens. Cat. No. 3092 measures 145 mm. long and 54 mm. deep, a ratio of 2.68, while Cat. No. 1533 is 92 mm. long by 35 mm. deep, a ratio of 2.62. The third, Cat. No. 1405, is 126 mm. by 51 mm., relatively the deepest of the three, with a ratio of 2.47. The average for this species is 2.8, while for *D. pectorosus* Cope it is 2.4. These three specimens approach the latter species in body proportions and yet do not exhibit the other characters of that species. Therefore I prefer to place them in the *D. analis* Cope group for the present, on the basis of the general characters, other than depth, which they show.

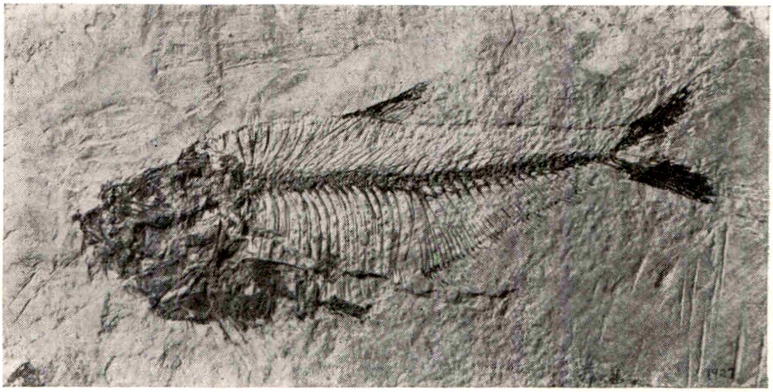

Fig. 2. *Diplomystus analis* Cope. Cat. No. 1927 Y. P. M, 1/3 nat. size.

Diplomystus theta Cope.

The type of this species lacks the posterior part, in consequence of which a clear definition of the form cannot be given. Professor Cope in 1884 thought it quite possible that this species was identical with *D. analis*, and I so consider it. If this is the case, then *D. analis* is a synonym of *D. theta* which was described three years previously. The description given by Cope falls well within the limits of the deeper-bodied specimens which I have referred to *D. analis*, for example, Cat. No. 1405, previously noted.

Diplomystus pectorosus Cope.

Specific characters: Dorsal fin, 8-9 rays; pectoral, 11 rays; pelvic, 7-8 rays; anal, 40-44 rays. Abdominal vertebræ, 16-17; caudal, 22. Ratio of maximum depth to total length, 3.-3.5; total length less caudals is 3.6 times that of head.

Ten specimens here seem to represent this species, although there is no clear line of demarcation between this and *D. analis* Cope. Seven of these were collected in Bear Lake Valley and the others from north of Evanston, in 1877. The pelvic fin is small, as in the other species of the genus. Cat. No. 3023 has 26 ventral scutes between the head and pelvic fin.

If we place *D. theta* with *D. analis,* it is still extremely difficult to find valid specific characters upon which to define the Green River species of *Diplomystus*. The bones of the skull are seldom in place, due to accidents in preservation, the rays of the fins do not vary beyond what might be expected within one species, and their position is relatively the same in all.

Knightia Jordan. Type *K. eocæna* Jordan.

In 1884 Professor Cope considered that two of the species of *Diplomystus, D. humilis* and *D. alta,* belonged in a separate division from the four species above described. It remained for Doctor Jordan in 1907 to erect a new genus, *Knightia,* for the reception of these two species. The specific name of the type species, *Clupea humilis* Leidy (*Clupea pusilla* Cope), being preoccupied, it was renamed *eocæna* by Jordan.

Generic characters: Dorsal scutes, according to Jordan, "are not wider than long, and there is but a single median tooth, at the end of a median longitudinal carina," characters seldom observable in the Yale specimens; lower jaw less prominent and the cleft of the mouth not so oblique as in *Diplomystus*; no teeth known; body moderately elongate, with the superior and inferior outlines not especially prominent; scales larger and smooth, about 35 rows; total number of vertebræ, 34-36; dorsal fin, 11 rays, anal about 14 rays, thus making the caudal section of the body much shorter than in the allied genus; pelvic fin well-developed, originating on a line a little posterior to the origin of the dorsal; pectoral fin much nearer the inferior border than in *Diplomystus*. Total length, 31-150 mm.

Key to Species.

K. eocæna Jordan: Moderately fusiform; 31-150 mm. long and 8-39 mm. deep. Ratio 3.-4.1, average about 3.4.

K. alta (Leidy): Deep-bodied; 54-103 mm. by 19-39 mm. Ratio 2.4-2.9, average about 2.7.

K. copei Tanner: Deep-bodied; 114 mm. long and 45.6 mm. deep. Ratio 2.6 (computed from figure).

Knightia eocæna Jordan.

Specific characters: Pectoral fin, 12-13 rays; pelvic, 7 rays. Abdominal vertebræ, 21; caudal, 13. Average ratio of depth to total length, 4.

There are 166 representatives of this species in the collection, with ratios of length, minus caudal fin, to depth as follows: 45 (27 per cent), a ratio of 3.; 14 (8 per cent), 3.1-3.4; 17 (10 per cent), 3.2; 19 (11 per cent), 3.3-4.41 (very young); 8 (5 per cent), 3.5-3.6; 7 (4 per cent), 3.7; and 15 (9 per cent), 3.8. In summary, approximately a fourth fall between 3. and 3.1, and nearly all the remainder between 3. and 3.5 inclusive. The immature specimens are very long and slender, with a ratio of 4.-4.1.

Cat. No. 1442 bears a supposed coprolite. It is a compact mass, 33 mm. long and 7 mm. wide, in maximum dimensions.

There are eight ventral scutes between the pectoral and pelvic fins and seven between the latter and the anal fin.

This was apparently the most common species of the genus in the Green River lakes, if we may judge from the relative abundance of its remains collected at Evanston, Bear Lake Valley, Green River, Twin Creek, and elsewhere in that area.

Knightia alta (Leidy).

Specific characters: The relatively deeper body of this species and its somewhat smaller average size are the main characters distinguishing it from the preceding species. The ratio of total length to depth is about 3.5.

The Marsh Collection contains 75 specimens from the Bear Lake Valley—Evanston area. The ratios of length, less caudal fin, to depth are as follows: 10 (13 per cent) have a ratio of 2.5; 18 (23 per cent) 2.6-2.7; 22 (30 per cent), 2.8; and 6 (8 per cent), 2.9.

Cat. No. 1512 (Fig. 3) is an unusually deep-bodied specimen, being 88 mm. long and 36 mm. deep, with a ratio of 2.4. Otherwise it does not seem to depart from the typical characters.

Knightia copei Tanner.

Specific characters: Heavy set throughout, with a greater depth in the caudal region than *K. alta*; length of head enters total length, less caudals, about four times and the depth two and a half times; total length 114 mm. and depth 45.6 mm. Abdominal vertebræ, 20; caudal, 14; dorsal fin, 15 rays, set vertically over pelvic fin; ventral scutes well-developed; dorsal scutes, if any, not preserved (auct. Tanner).

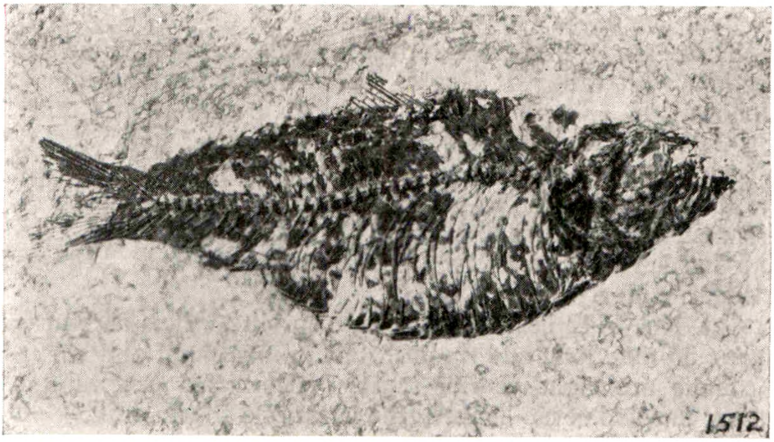

Fig. 3. *Knightia alta* (Leidy). Cat. No. 1512 Y. P. M. about nat. size.

The type is No. 11 of the University of Utah Fish Collection. Several specimens in the Yale Museum show a relatively greater depth in the caudal region than does the typical *K. alta,* and yet I cannot discern sufficiently great distinctions to separate them from the latter. For example, Cat. No. 1512 (Fig. 3) is so short and relatively deep-bodied that by itself it might almost be considered a separate species, but among the 75 specimens which I have identified as *K. alta* are all gradations from this at one extreme to the more slender forms which approach *K. eocæna.* In fact, it is almost impossible in a large series of specimens definitely to place any line of demarcation between the species. In this study it has seemed advisable to place all of the specimens with a body ratio between 2.4 and 2.9 inclusive in *K. alta* and those between 3. and 4.1 in *K. eocæna.* The other limiting factors seem to coördinate with these ratios.

Osteoglossidæ Bonaparte.

Phareodus Leidy = *Dapedoglossus* Cope.

Type P. acutus Leidy.

Generic characters: Oval to elongate oval in outline, possessing a single row of long, slender teeth; mouth short; dorsal fin over anal, pectoral fin with an elongated first ray, and scales characteristic of the Osteoglossidæ, to which family this genus is at present referred, although further study may prove that it belongs to a separate family. Of the living genera it apparently resembles most closely the *Heterotis* of Africa. It is interesting to note that this genus and *Diplomystus* have living representatives now so remote from this ancient Green River basin.

Key to Species.

P. acutus Leidy (syn. *P. testis* Cope): First pectoral ray with serrate inner border, unusually developed. Teeth 18-24. Fin ray formula, D. 19-23, A. 27-30. First ray of dorsal fin over sixth anal ray. Vertebræ, Ab. 18; C. 24-25. Length, 112-482 mm.; depth, 38-180 mm.
Bear Lake Valley, Evanston, and Fossil.

P. æquipinnis (Cope): First pectoral ray not especially well developed. Fin ray formula, D. 22-23, A. 22. Vertebræ, Ab. 19; C. 27. Length, 51-92 mm.

P. encaustus (Cope): Length, 3-4 feet. Scales up to 29 mm. in diameter. Complete specimen unknown.

Phareodus acutus Leidy (= *P. testis* Cope).

The type specimens of Leidy consist of premaxillaries, dentaries, and a maxillary, all with teeth, while Cope's *P. testis* is based on more complete specimens. The larger fishes referrable to Cope's form show teeth similar to Leidy's specimens, and since Leidy's precedes Cope's species by four years, I believe that Leidy's name is valid and that these two forms are conspecific.

Cat. No. 3002 (Fig. 4), a nearly complete specimen, has 18 teeth and the first ray of the pectoral fin quite long and stout.

DIMENSIONS IN MILLIMETERS.

Total length, partly estimated	318.
Total length, less caudal fin	262.
Maximum depth	128.
Length of head	76.
Length of first pectoral ray	78.5
Length of largest scales (vertical)	12.

Another nearly complete specimen, Cat. No. 3011, is one of the largest known. Unfortunately a portion of the anterior part of the muzzle is missing, so that the present total length is 343 mm., with a depth of 147.5 mm. The length of the head, as now preserved, is 78.5 mm.

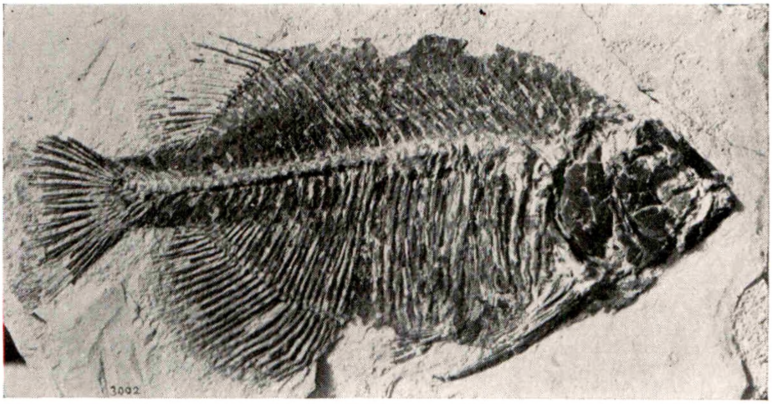

Fig. 4. *Phareodus acutus* Leidy. Cat. No. 3002 Y. P. M. About 1/3 nat. size.

Cat. No. 3027 consists chiefly of the skeletal impression in the matrix, but it is unusually perfect. The specimen is smaller than any recorded, being 153 mm. long and 57.5 mm. deep. It has 7 small pectoral rays, 6 pelvic, 26 anal and 21 dorsal. The latter two figures show one less ray than the minimum number normal to *P. testis.* The number of teeth is 17, and of the vertebræ 18 are abdominal and 24 caudal. It may be a submature individual.

All of these specimens, except in instances otherwise noted, were collected near Evanston in 1877.

Cat. No. 2998 is 210 mm. long and has a depth of 73 mm., but it has only 24 anal and 19 dorsal rays, with 22 caudal and 18 abdominal vertebræ. Thus it has fewer fin rays and caudal vertebræ than normal. The pectoral fin has 10 rays now present, but the long first pectoral ray is missing.

Cat. No. 1928 and 1929 are two complementary slabs. The bones have been so disturbed that little can be determined from them. Apparently it is the smallest example of this species so far recorded, with a length of 112 mm. and a depth of approximately 38 mm. It is probably an immature individual.

Cat. No. 1935 is a skeletal impression, 215 mm. long and 83 mm. deep. The length of the first pectoral ray is 60 mm.

The following three specimens came from Bear Lake Valley and were collected in 1877. Cat. No. 3014 is a typical specimen, 178 mm. long, with a depth of 64 mm. The pectoral fin has 10 rays, without the long first ray. The maximum length of the teeth is 2 mm. and the width 7 mm. Cat. No. 1633 is 247 mm. long and 120 mm. deep, hence unusually deep-bodied. The belly scales are well shown, being 8 mm. in vertical by 5 mm. in horizontal diameter. There are but 19 dorsal fin rays, but this may be due to imperfect preservation, although Cat. No. 1635, a medium-sized specimen 173 mm. long, also has 19 dorsal rays. This number seems to be characteristic of the smaller specimens of the species.

One of the best-preserved examples is Cat. No. 2186. It is next to the longest on record, 15½ inches over all, while the longest is 19 inches. The length of the head is 101 mm., and the total length, less caudal fin, is 323 mm., while the depth is 130 mm. There are 24 teeth in the upper jaw and 16 in the lower. The dorsal fin rays number 23, the anal 26, and the caudal 20. The very stout and robust first pectoral ray is preserved for but 61 mm. of its length, although it must have exceeded this in total length.

Pharcodus brevicaudatus n. sp.

Specific characters: First rays of dorsal and of anal fin are in a vertical line, whereas in the preceding species the first dorsal is over the sixth anal. The outline is more elongate or more fusiform than the other. The size is that of the smaller examples of *P. acutus*, varying in the Museum's specimens between 141 and 167 mm. and the depth from 52 to 54.5 mm. Vertebræ, Ab. 18; C. 20.

Cat. No. 1636 is a splendid specimen, except that the bones of the anterior part of the skull have been considerably disturbed. There are 22 anal and 20 dorsal rays. The first pectoral ray (31 mm. long) is well-developed, and there are five rows of scales above the vertebral column and nine below. Cat. No. 1418 (Fig. 5) is slightly smaller but otherwise similar in all characteristics, except that it has 25 anal rays. The length of the first pectoral ray is 32 mm. These are cotypes.

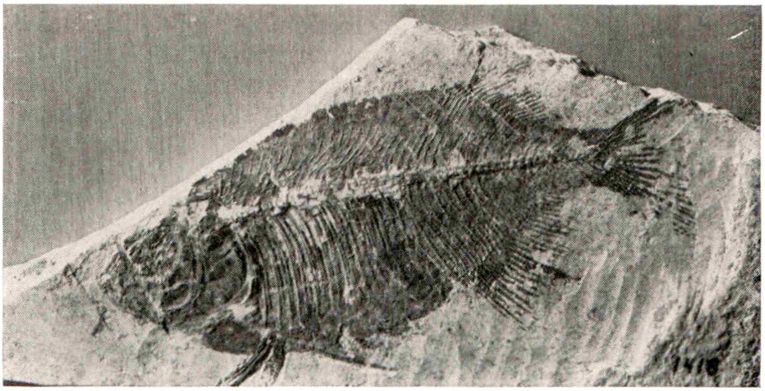

Fig. 5. *Phareodus brevicaudatus* n. sp. Cotype Cat. No. 1418 Y. P. M. About ½ nat. size.

Priscacaridæ Jordan.

Priscacara Cope. Type *P. serrata* Cope.

Generic characters: Rays, 10 or 11 stout dorsal and 3 anal spinous, followed by 9-14 soft rays in the former fin and 8-11 in the latter; caudal fin compact and slightly rounded. Vertebræ, Ab. 7-10; C. 13-16. Oval to elongate elliptical in outline, varying from 62 mm. to 350 mm. in length and from 16-129 mm. in depth. Minute conical teeth along the margin of both jaws. Preoperculum serrate on free borders. Scales ctenoid with concentric grooves, the rough surface finely granulated and the shape longer than deep. The group seems to be confined to the Eocene. The genus is divided into two groups, one with strong ventral spine and fewer soft dorsal rays and the other with weak ventral spine and an increased number of soft rays in the dorsal fin.

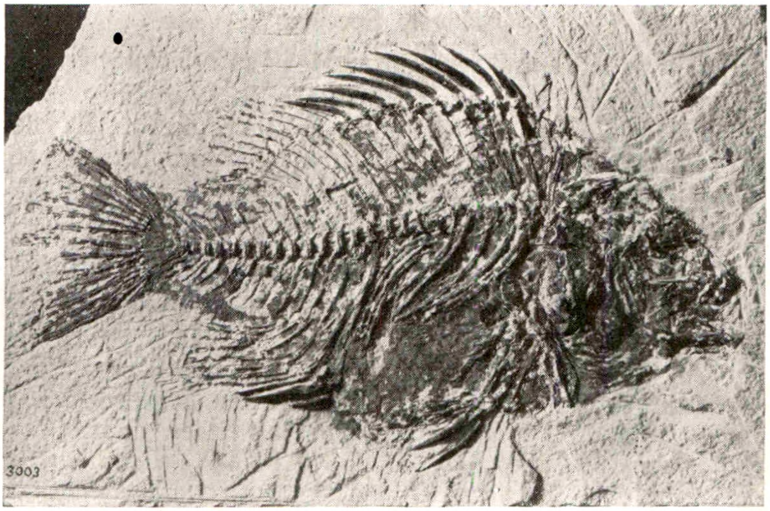

Fig. 6. *Priscacara serrata* Cope. Cat. No. 3003 Y. P. M. About 1/3 nat. size.

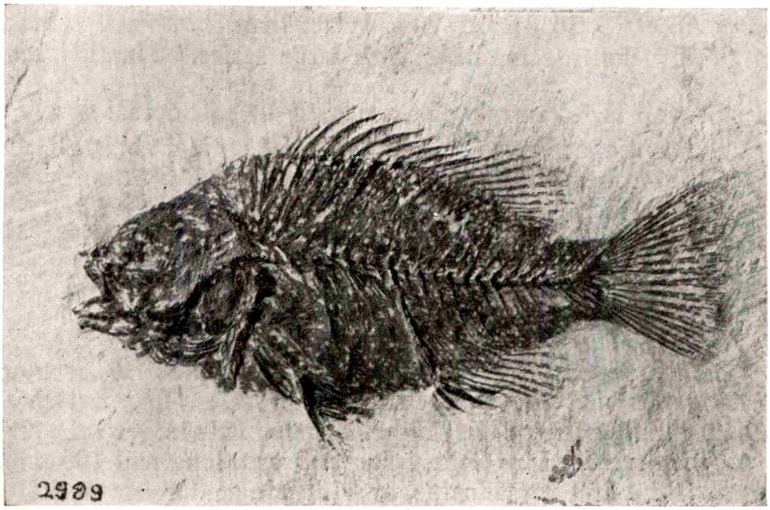

Fig. 7. *Priscacara oxyprion* Cope. Cat. No. 2989 Y. P. M. 4/7 nat. size.

Key to Species.

Section I. Ventral spine strong, 9-12 soft dorsal rays.

P. serrata Cope: Rays, D. X-11, A. III-10. Vertebræ, Ab. 9; C. 14. Length 217-269 mm., 2.4 times depth. Regular wide oval in outline, with subequal contraction at both extremities. Evanston and Twin Creek.

P. cypha Cope: Rays, D. XI-10.11, A. III-9. Vertebræ, Ab. 8-9; C. 14. Size about that of *P. serrata* but dorsal outline more convex, relatively longer head, and operculum covered with scales. Evanston and Twin Creek.

P. dartonæ Eastman: Rays, D. XI-11, A. III-8. Vertebræ, Ab. 10; C. 15. Length 350 mm., 2.7 times depth. Steep facial profile. Intermediate in characters between *P. oxyprion* and *P. clivosa* but larger than either. Fossil.

P. hypsacantha Cope: Rays, D. X-9, A. III-9. Vertebræ, Ab. 10; C. 14. Smallest of the genus, with average length of 62 mm., 3.4-3.8 times depth. Elongate spinous ray beginning second dorsal fin. Twin Creek.

P. oxyprion Cope: Rays, D. X-11, A. III-8. Vertebræ, Ab. 10; C. 14. Length 137-154 mm., averaging 2.74 times depth. Elongate oval in outline. Bear Lake Valley, Evanston, and Twin Creek.

P. testudinaria Cope: Rays, D. XI-12, A.-21+. Vertebræ, Ab. 8; C. 16. Large as or larger than *P. serrata.* Markedly elongate in form, with large scales. Manti, Utah.

Section II. Ventral spine weak, 13-14 soft dorsal rays.

P. clivosa Cope: Rays, D. X-13, A. III-11. Vertebræ, Ab. 8; C. 14. Length 114-138 mm., averaging 2.6 times depth. Steep facial profile, Evanston, Fossil, and Twin Creek.

P. pealei Cope: Rays, D. X-14, A. III-11. Vertebræ, Ab. 7-9; C. 14. Length 130 mm., 2.6 times depth. Similar in outline to *P. serrata.* Evanston and Twin Creek.

Cat. No. 3003 (Fig. 6) is a very fine example of *P. serrata,* clearly showing the character of the scales, fins, vertebral column, and many of the skull elements. It is larger than any specimen recorded by Cope, being 269 mm. long and 108 mm. deep at the first dorsal spine, or 113 mm. at the ventral fin.

Cat. No. 3029 is a typical example of *P. cypha.* It lacks a portion of the superior median outline, although an impression of much of this may be seen in the matrix. There are at least

8 and probably 9 abdominal vertebræ, exact determination being difficult owing to the somewhat disturbed condition of the area in this specimen. One of the pharyngeal bones is clearly shown with its very small conical teeth.

Cat. Nos. 2989 (Fig. 7) and 3004 are splendid specimens of *P. oxyprion.* Both are slightly larger than the type, one being 154 mm. long and the other 145 mm.

Three nearly complete specimens show the characters of *P. clivosa,* bearing the Cat. Nos. 2839, 2992, and 2995. The first, the largest, is 138 mm. long and the second 114 mm.

Cat. No. 2993 is a typical example of *P. pealei.*

Cockerellites Jordan. Type *Priscacara liops* Cope.

The type and only species in this genus is characterized by having 9 abdominal and 13 caudal vertebræ. The fin radii are D. X-13.14, A. III-10.11. The outline is similar to that of *Priscacara serrata,* and the length averages 2.6 times the depth. The total length varies from 117 to 123 mm. and the maximum depth from 46.5 to 55 mm.

Five specimens in the Marsh Collection represent this form, which is known from Bear Lake Valley, Evanston, and Twin Creek.

Percidæ Bonaparte.

Mioplosus Cope. Type *M. labracoides* Cope.

Generic characters: Of the same family as *Perca,* differing from that genus mainly in having fewer vertebræ and the operculum spineless; two dorsal fins; inferior border of preoperculum with teeth; also small single series of teeth on premaxillary and dentary; elongate in outline, with ctenoid scales.

Key to Species.

M. abbreviatus Cope: Rays, D. IX-1.11, A. II-11, P. 14. Vertebræ, Ab. 9; C. 14. Depth at first dorsal ray enters total length 3½ times, and depth at first anal ray enters vertebral length 2.8 times. Length of vertebral column 125 mm.

M. labracoides Cope: Rays, D. IX-1.12, A. II-14, V. 1-5, C. 8-17-8. Vertebræ, Ab. 10; C. 15. Depth at first dorsal ray enters total length 4 times and at first anal enters vertebral length 3 times. Five teeth on inferior border of preoperculum. Total length 144 mm. to 440 mm.

M. longus Cope: Rays, D. IX-12, A. II-12. Vertebræ, Ab. 10; C. 15. Depth at first dorsal ray enters total length 5 times and at first anal 3.5-3.8. Three large and two small teeth on inferior border of preoperculum. Total length 81-175 mm.

M. beani Cope: Rays, D. IX-1.13, A. II-12, P-13. Vertebræ Ab. 10; C. 15. Depth at first dorsal ray enters total length 6 times. Depth at first anal ray enters vertebral length 4+ times. Total length 131 mm.

M. sauvageanus Cope: Rays, D. VI+-14, A. I-9. Vertebræ, Ab. 11; C. 16. Depth at middle of first dorsal enters total length nearly 5 times and vertebral length 3.8 times. Elongation of muzzle beyond lower jaw. Average size of *M. labracoides* but more vertebræ and fewer soft rays.

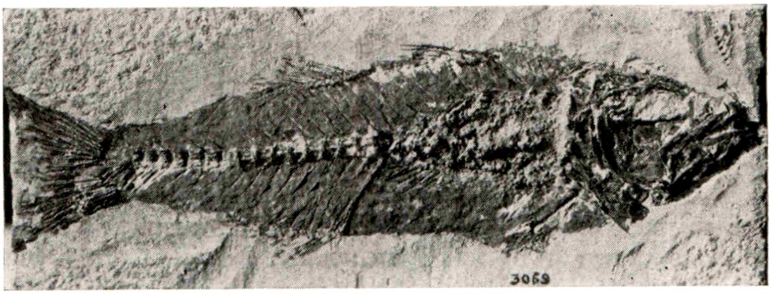

Fig. 8. *Mioplosus labracoides* Cope. Cat. No. 3069 Y. P. M. Slightly less than ½ nat. size.

M. labracoides Cope.

The largest example of this species in the collection, Cat. No. 3069 (Fig. 8) so far prepared is 229 mm. long and 54 mm. deep at the first anal ray. It is therefore considerably smaller than the type. Cat. No. 1609 lacks part of the end of the muzzle. It is 144 mm. long (partly estimated) and 35 mm. deep at the first dorsal ray. The specimen is nearly half the size of the type (280 mm. long) but shows all the proportions and characters of the larger ones. There are five rows of scales above and below the vertebral column at the caudal peduncle. The color of the scales on this specimen is dark to medium light brown, and in fact all the specimens of various genera with scales present from Bear Lake Valley and Southward show the same coloration. It may or may not give a clue to the external appearance of these fishes in life. Cat. Nos. 1690 and 3070 also represent this species.

M. longus Cope.

There are six specimens which I have tentatively identified with this species. It is my opinion that these forms represent the young of *M. labracoides*. I cannot detect any real difference between the two species, except that the former is somewhat more slender in proportions, but on the other hand the ratios of one grade into those of the other. Cope's statement that the anal fin of *M. longus* has two less soft rays does not seem to be a constant character.

Cat. Nos. 1537 and 3071 have a length to depth ratio of about 5, the former being 130 mm. long and 26 mm. deep at the first anal ray, while the latter is 159 mm. and 30 mm. in the same dimensions. Both are smaller than the type (175 mm. long) but are otherwise like it. The other four specimens are intermediate in proportions between the types of the two species. Cat. No. 1610 has a ratio of 4.3; Cat. Nos. 1701, 1807, and 1923 a ratio of 4.5. Cat. No. 1701 seems to be the smallest recorded, being 81 mm. long and 19 mm. deep.

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THE PROBLEM OF THE CARBONATE-APATITES; A CARBONATE OXY-APATITE (DAHLLITE).

DUNCAN McCONNELL.

ABSTRACT.

A number of investigations have been concerned with the carbonate-apatites and the results are contradictory in some cases. The existence of carbonate-apatites has been questioned as well as the existence of oxy-apatites.

Gruner and McConnell investigated francolite through the use of chemical and X-ray methods and arrived at some entirely new conclusions regarding the structural conformity of this substance with fluor-apatite. Their conclusions were based on a single analysis and, for this reason, it seems desirable to extend the investigation to dahllite.

The conclusions regarding the existence of CO_4-groups are further substantiated. The water of this compound bears a rather complex relationship to the other constituents. There can be no further doubt regarding the existence of the carbonate-apatite or oxy-apatite molecules, although neither of these molecules exists as an ultimate end-member but is dependent upon complex inter-relationships with one another or with other apatite molecules. The isomorphism in these compounds is extremely complex.

INTRODUCTION.

An investigation of the problems concerning carbonate-apatites was begun several years ago as an integral part of a more general study of the isomorphism of the apatite group. The carbonate-apatites are of more than passing interest because there has been considerable debate as to their existence. Those who have participated in the discussion have arrived at two entirely different conclusions:

(1) That all CO_2 associated with phosphatic materials is to be accounted for as contaminating carbonate minerals (calcite or aragonite), or

(2) That the CO_2 is an essential constituent of certain special members of the apatite group.

One phase of the investigation of the carbonate-apatites, which was a collaboration, has appeared (1). This work demonstrated that the CO_2 could be accounted for in terms of the crystal structure of apatite and recorded a most complete analysis of a pure homogeneous crystalline mineral which contained 3.36 weight per cent of CO_2. This amount of CO_2 cannot possibly be accounted for in terms of a contaminating carbonate mineral, and there was no microscopic evidence of contamination of any sort. This work permitted certain conclusions regarding the structural position of the *C*-ions within the structure.

TABLE I.

Chemical Analysis of Dahllite, from Mouillac, France.

	1 Weight % of oxides	2 Ionic ratios		3 Number of ions in cell	4 Weights of ions
P_2O_5	38.57	P	5.430	5.300	164.4
SO_3	0.05	S	.006	.006	0.2
SiO_2	0.40	Si	.067	.065	1.8
Al_2O_3	0.44	Al	.086	.084	2.3
CO_2	4.46*	C	1.014	.990	11.9
CaO	53.16	Ca	9.481	9.254	370.8
Na_2O	0.77	Na	.248	.242	5.6
K_2O	0.28	K	.060	.059	2.3
F	0.19†	F	.100	.098	1.9
Cl	0.02	Cl	.006	.006	0.2
H_2O + 300°	0.51‡	OH	.567	.553	9.4
H_2O (110°-300°)	0.21‡		.233		
H_2O — 110°	0.48‡		.533		
Fe_2O_3	0.34				
	99.88			O = 25.343	405.5
Less O	0.08				
	99.80			42.000	976.3

* CO_2 determined on a different sample by Dr. R. B. Ellestad gave 4.35%.

†Determined by Dr. W. D. Armstrong.

‡ Determinations on a different sample by Dr. R. B. Ellestad gave: H_2O + 300°, 0.50%; H_2O (110°-300°), 0.50%; H_2O—110°, 0.61%.

The oxy-apatite [voelckerite] molecule also has been a matter of some controversy and a number of writers have debated its existence because its structure could not be satisfactorily accounted for (2) and the pure material could not be synthesized although mixtures containing as much as 60-70 per cent of this molecule were obtained (3). The oxy-apatite molecule undoubtedly does exist (4 and 6), however, and the writer has obtained a partial explanation, at least, resulting in a new formula, $(Ca, X)_{10}O_2(PO_4)_6$, where X represents an ion with a positive charge greater than two. It has been postulated that this ion may be carbon in some instances (4). In a later work the writer has given an alternate formula: $Ca_{10}O_2(P, X)_6O_{24}$ where X is an ion with a positive charge greater than five (5).

In view of the apparent interest in these earlier conclusions it has seemed desirable to resolve the problem further in terms of a new and rather complete analysis which has been obtained. The sample used in this study was obtained through the kindness of Dr. A. Lacroix, of the Muséum National d'Histoire Naturelle, Paris. It is labelled dahllite from Mouillac, France, and, although it is somewhat different from the original type material analysed by H. Bäckström (7), nevertheless, dahllite is probably the most satisfactory name that can be applied to it.

This investigation was made possible through a grant by the Committee on Research and Publications, The University of Texas. The writer wishes to acknowledge the kindness of Dr. R. B. Ellestad in furnishing several analytical determinations and of Dr. W. D. Armstrong in furnishing a determination of fluorine using a method developed by him (8).

MEGASCOPIC AND MICROSCOPIC DESCRIPTION.

The color of the dahllite is creamy white to milky white [bluish] but the mineral contains, within numerous interconnecting cavities, a superficial iron staining [limonite?]. The specimen is composed of a complex system of radial fibers. It is very tenacious rather than brittle when struck with a hammer.

In thin section the material appears slightly cloudy and not completely colorless. This cloudiness may be caused by air spaces or extremely small quantities of impurities between the fine fibers. If any impurity is present in addition to the iron staining, it is probably a very small amount of kaolinite or a related mineral.

There is no evidence of the presence of any impurity which might contain CO_2 and it can be concluded with certainty that calcite and aragonite are entirely absent, because no mineral with high birefringence is present in quantities capable of detection under the microscope and the *x*-ray powder diagrams did not show lines of calcite or aragonite. To account for the CO_2 obtained in the analysis it would be necessary for about ten per cent of the material to be $CaCO_3$. If this amount of impurity were present it could certainly be detected by one or the other or both of these methods.

The refractive indices are slightly variable, the highest observed value being about 1.628 and the lowest about 1.619 for yellow light (Wratten filter no. 90). Although the birefringence is probably not as great as the difference between these values, nevertheless, it is somewhat greater than that of ordinary fluor-apatite.

The density was obtained by several determinations using a fused silica pycnometer and tetrahydronapthalene, and by using Thoulet's solution and an electric centrifuge. It was not possible to check duplicate determinations using the same method and the two methods yield values which do not satisfactorily agree. Because most reliable checks have been obtained by duplicate determinations and determinations made by both of these methods on other substances, it can safely be concluded that the difficulty lies in the nature of the material. Probably the best value was obtained by the pycnometer method and this is 2.93. This value is probably too low because of water or air spaces which were included within the very fine fibrous texture of the mineral, in spite of the fact that the determinations were made on powder retained on a 100-mesh screen.

CHEMICAL AND X-RAY DATA

A chemical analysis of material from the same locality, and supposedly similar, was made by F. Pisani (9, p. 1390) with the following results:

CaO	P_2O_5	CO_2	$\underbrace{Al_2O_3 + Fe_2O_3}$	H_2O	F	Sum
53.65	38.40	5.30	0.57	2.10	trace	100.02

A new analysis was obtained from Ledoux and Company, New York, New York, which differs somewhat—most notably with regard to the water content and CO_2. The results of the determinations are given in column 1 of Table I.

As mentioned above the mineral is contaminated by iron oxide. For this reason the Fe_2O_3 has been deducted from the analysis for the purpose of the computations. The possibility of a very small amount of contamination by a clay mineral has been mentioned but the Al_2O_3 and SiO_2 have not been deducted from the analysis because these oxides can occur in the phosphate mineral and because the assignment of Al^{3+} and Si^{4+} to the phosphorus positions makes certain conclusions regarding the carbon more valid than they would otherwise seem, were these ions to be disregarded. The probability of the existence of alkali-apatites has been demonstrated (5) and there is no evidence that the alkalies are present in the form of impurities. Consequently the alkalies are used in the calculations.

The number of ions relegated to the 42 ionic positions of fluor-apatite is indicated in column 3. Column 4 contains the weights used to ascertain the molecular weight of the unit cell.

The interplanar distances obtained by the powder method using FeK_α have been given elsewhere (5). These measurements yield lattice dimensions: $a_0 = 9.41 Å$; $c_0 = 6.88 Å$; $c = 0.731$. Using 976 for the molecular weight the theoretical density,

$$\rho = \frac{976 \times 1.649}{528} = 3.048$$

The agreement of this value with the measured value 2.93 is not satisfactory by virtue of the difficulties which attend the experimental determination of the density and which have been mentioned.

The most interesting hypothesis advanced by Gruner and McConnell (1) and by the writer (4) is that concerning the tetrahedral configuration of carbon in the structure of francolite and ellestadite. The present investigation offers further support of this hypothesis, because, even when all of the aluminum and silicon ions are assigned to phosphorus positions, it is necessary to assume that a significant number of the phosphorus positions are vacant or occupied by carbon. The improbability of vacancies in these positions has been discussed (1) and will not be considered further here.

Vernadsky (10) has extended some of the writer's conclusions (4) to alumino-phosphates and alumino-sulfates and has presented an interesting question regarding the probability of the existence of alumino-carbonates [having CO_4-groups analogous to the SiO_4-groups of alumino-silicates]. Although the implications to be drawn from an hypothesis stipulating a tetrahedral configuration for carbon are interesting, to be sure, it must be recalled that this configuration is not the most stable one (1) and probably does not exist except to a limited extent in certain special sorts of compounds, Furthermore, it is to be remembered that, although this is the third compound for which such a configuration has been postulated, the proof is indirect and has not been demonstrated except for members of the apatite group.

Although one could readily advance the supposition that CO_3-groups enter the apatite lattice in the fluorine positions on the basis of the ionic ratios obtained here (Table I), this is not tenable for several other reasons which have been given by Gruner and McConnell (1) and by the writer (5).

The mineral is a carbonate-apatite, to be sure, but it does not contain sufficient water to fill the fluorine positions of the apatite structure. It is necessary, on this account, to assume that the oxy-apatite molecule is present also. Even if all the water found (H_2O—110°, H_2O+110°, H_2O+300°) were assumed to enter the structure as hydroxyl ions there would still be a significant deficiency which would have to be accounted for in terms of the oxy-apatite molecule.

The determinations of CO_2, H_2O+300° and H_2O—110° by the two analysts show excellent agreement, but the determinations of water between 110° and 300° differ by slightly more than 100 per cent.[1] This lack of agreement possibly could be interpreted as error on the part of one of the analysts but the writer does not hold to this opinion. Because the water determinations were not made on the same sample, these differences seem to bear out certain suppositions which arose from previous experiences with the liberation of water from fibrous minerals of this sort. A most plausible explanation is as follows:

(1) The water above 300° is present as OH-groups in the apatite lattice and this amount is rather stable, showing little if any variation below 300° C.

(2) The amount of hygroscopic water below 110° is somewhat variable, to be sure, but does not vary greatly with different samples of the same material which have been allowed to approach equilibrium with the atmosphere. Furthermore, the amount of this water does not vary greatly under normal humidity conditions.

(3) The water liberated between 110° and 300° depends to a considerable extent upon the texture of the mineral material and is appreciably altered by the method used to prepare the sample. This water is very firmly held by superficial forces but probably is not present as OH-groups in the crystal

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[1] Water was determined by different methods by the two analysts. Ledoux and Company determined the water between 300° and 1000° by electrically heating the specimen in a silica tube and weighing the water. Dr. Ellestad determined the total water by Penfield's method using a lead oxide flux. The moisture was determined as loss in weight at 108° C. after heating for 3 hours and again after heating for 17 hours. The water between 108° and 300° was determined as loss in weight on heating in an electric oven for 18 hours.

lattice. This supposition could account for the significant differences in the total water as determined by the three analysts: Ledoux and Company, 1.20; R. B. Ellestad, 1.61 and F. Pisani, 2.10. The first two of these analysts have already been shown to agree remarkably well on water determined outside of this temperature range.

Quite admittedly the selection of 300° as the optimum temperature for distinguishing between the water present as OH-groups in the structure and the water of the third sort, is an arbitrary one and has no particular theoretical justification, but the mere fact that it is possible to obtain checks at temperatures above 300° but apparently not possible to obtain checks below this temperature is believed to be significant.

The reasons given above are the basis on which the water below 300° is excluded from the calculation of the statistical distribution of the ions in the 42 theoretical positions of apatite. This distribution is as follows:

$$\begin{aligned}
10\ \mathrm{Ca} &= 9.25\ Ca + .24\ Na + .06\ K + .45\ C \\
6\ P &= 5.30\ P + .01\ S + .08\ Al + .07\ Si + .54\ C \\
2\ F &= .10\ F + .01\ Cl + .55\ OH + 1.34\ O \\
24\ O &= 24\ O
\end{aligned}$$

CONCLUSIONS.

The name dahllite should be extended in its connotation to include a carbonate oxy-apatite as well as a carbonate hydroxy-apatite. A detailed account of the study of a specimen of dahllite has been presented in order further to substantiate evidences already reported for other carbonate-apatites, but many of the more detailed considerations have not been included here.

On the basis of this study all of the conclusions previously set down seem increasingly justifiable with one notable exception. The specimen of dahllite considered here was previously considered by the writer (5) to be a carbonate hydroxy-apatite on the basis of Pisani's analysis. Although Pisani's analysis is essentially correct in some of its constituents, it is sufficiently wanting in others to have resulted in this erroneous conclusion. Possibly this demonstrates the futility of basing detailed considerations upon analyses which have not been made according to more recent procedures, even though produced by quite reliable analysts at a somewhat earlier date. On the other hand it may indicate that similar samples from the same locality, although supposedly identical, may differ as greatly as the determinations by Pisani and Ledoux and Company. The former of these propositions seems the more reasonable in this case.

The hypothesis, previously advanced, which requires a tetrahedral configuration for carbon in compounds of this type, has received additional support through this investigation. The occurrence of CO_4-groups is interesting but this supposition cannot be extended to other structures by way of analogy without the use of most complete and reliable analytical data, because no method is available at present for the direct location of carbon ions in structures of this complexity.

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RADON CONDENSATION METHOD OF DETERMINING GEOLOGIC AGE.

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ABSTRACT.

A modified method of determining the helium age is described which overcomes the two criticisms of the two methods previously described. The danger of contamination or removal of radon during the chemical procedure is eliminated by condensing the radon directly from the fluxed rock. Another advantage is that all of the determinations can be made on the same specimen, thus lowering the errors due to inhomogeneity. Some preliminary results of radon determinations and the comparison of the results by three methods on a specimen of the Quincy granite are given.

All methods of determining geological time depend upon the measurement of the rate of some naturally occurring process, and the calculation of the time since it began by comparing the present change per unit of time with the measured total effect produced in the past. Of the various methods which have been employed, the most accurate are those which measure the extent of decay of the naturally occurring radioactive elements. In computing the geologic age it is assumed that the total rates of decay have been uniform in the past, or have varied in a known way, and that the measured end product was derived entirely through this measured-rate process.

Two methods for calculating the age of a rock from determinations of the amount of helium accumulated from the radioactive constituents have been described. The first determines the amount of helium and its rate of production in the specimen by direct alpha ray counting from a thin deposited film of the rock.[2] The age is computed by dividing the total number of helium atoms present by the number of alpha particles emitted per unit of time for equivalent masses of material. For all the old rocks, corrections must be made for the wearing down of uranium, actino-uranium, and thorium, and this involves separate radium determinations.

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[1] Holder of Fellowship in Geological Sciences awarded by the Royal Society of Canada.

[2] Evans and Finney: Phys. Rev. 48, 503-511, 1935.

Goodman and Evans, Paper presented before Physical Society, Washington, D. C., April 29, 1938, to appear in Phys. Rev.

The second method measures the rate of production of helium indirectly. It involves the measurement of the helium evolved from the carbonate fusion of the ground rock, followed by separate determinations of the amounts of radium and thorium present in the hydrochloric acid solution of the fluxed material. The method used for the analysis of helium was developed by Paneth and Peters,[3] and the first age determinations were made by Paneth, Gehler, and Guenther.[4, 5] Later applications and improvements have been made by Paneth, Holmes, Urry, and the author.[5]

A criticism of this method has been that, since silica is known to adsorb radon, any trace of silica remaining in the final solution after the chemical treatment might introduce an error. The radon in equilibrium with the uranium series in the rock is permitted to escape during fusion, and since it is the most convenient member of the series to measure, it is allowed to build up again by storing the solution containing the parent radium in a closed flask (for 30 days or some other known period). The solution is prepared by adding hydrochloric acid to the residue containing radium carbonate, other insoluble carbonates, and silica, after filtering off the water-soluble compounds. The silica is removed by dehydration and filtration in the usual way, the precipitate washed, and more hydrochloric acid added. Since the quantities of radon measured with ordinary rocks are of the order of 10^{-12} curies, even a small trace of silica remaining after the chemical treatment would leave a relatively large surface, and might cause the removal of some of the radon. Any more direct method of measuring the quantity of rock radon would be a distinct improvement, not only for the above reason, but also because it would involve less risk of contamination by contact with foreign objects, and would not necessitate a correction for the accumulation constant. Such a method has been developed by Evans in the direct fusion technique, and the alpha count method of determining age. However, this method has the disadvantage that the helium and radium determinations and the alpha ray countings are done on separate samples of rock, and therefore inhomogeneities in the specimens would introduce uncertainties. While a recent co-operative research between the author and Goodman and Evans[6, 7] shows that, although these criticisms are not ordinarily serious, they may sometimes cause a considerable error, especially where the activity is low or the inhomogeneity marked. A modified direct method was therefore investigated which overcomes all of the above disadvantages, and in addition involves less danger of radium contamination and requires less time than the second method.

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[3] Paneth and Peters: Z. phys. chem. 134, 353; B1, 170 and 253, 1928.
[4] Paneth, Gehler, and Guenther: Z. Elektrochem, 34, 645, 1928.
[5] Paneth and Holmes: Proc. Roy. Soc. London A 154, 385, 1936.
Lane and Urry: Bull. G. S. A. 46, 1101, 1935.
Urry: ibid., 47, 1217, 1936.
Keevil: ibid., papers in press.

EXPERIMENTAL PART.

Instead of allowing the radon to escape from the rock during fusion, and later storing the acid solution in a special flask until equilibrium is reached or until a known amount of radon has accumulated, the radon is collected directly during fusion and condensed in a bulb, using a liquid nitrogen cooling bath (at—196° C.). The emanation, helium, and other gases may be swept into the evacuated bulb by opening and closing one of the stopcocks above the neck of the bulb a number of times until the gases are swept out of the furnace, or by streaming through a mercury bubbler. Condensation is very rapid, so that there is always a negligible pressure in the bulb (that due to minute quantities of helium and hydrogen). The gas pressure in the furnace, on the other hand, may reach one atmosphere. This difference of pressure and the continued evolution of gas from the sample after the helium and radon are expelled are sufficient to drive both of these gases into the bulb. The radon condenses at—62° C., and solidifies at—71° C.

In the flux method, the last traces of radon and helium are swept in by the CO_2 from the flux. If additional CO_2 is necessary, some source may be attached to the furnace. The flask may then be removed after closing the stopcock, and the emanation transferred at once for measurement in the ionization chamber. A small glass tip at the bottom of the bulb may be broken under rubber tubing for introduction of emanation-free nitrogen to fill the chamber completely. The other measurements necessary for an age determination, helium and thorium, may be made in the usual way. As it is preferable to measure all three quantities on the same sample, after closing off the furnace, the helium (which is not condensed) may be dis-

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[6] Evans, Goodman, Keevil, Lane, and Urry: Phys. Rev., in preparation.
[7] Keevil and Goodman: J. Geol., in preparation.

tributed throughout the apparatus, the liquid nitrogen bath being kept around the bulb. The bulb would then be shut off from the system and radon and helium measured directly. Calibrations of the helium apparatus would be made in the usual way, but the volume of the bulb would have to be taken into account and included in the calibration constant. The modifications necessary in the construction and manipulation of the helium apparatus will become obvious on consulting the recent description of its operation.[8]

The following results (Table I) indicate that the radon is condensed in an ordinary glass bulb at liquid nitrogen temperatures, and can be liberated by heating.[9]

TABLE I.

Lab. No.	Type of rock	Ra x 10^{18}—from solution method gm. per gm.	Ra x 10^{13} —from direct fusion method gm. per gm.	Ra x 10^{18} —by direct condensation gm. per gm.
HOK	Monchiquite	4.0	3.2	2
37	Basalt	1.4	1.6	≤ 4
Q2	Granite	11.1	9.4	12.2
		13.1		

In the first two samples the accuracy is low, due to the size of the correction applied for radon from the furnace parts. However, they serve as rough checks. The correction for radon from the furnace materials was determined from blank runs. In the last run, where the radon content is not so low, the agreement between the three methods is good. The correction for this pyrex vacuum furnace could hardly be reduced below 0.5 x 10^{-18} (equivalent in g. Ra per gram of sample), and this sets a limit of accuracy on the method using this kind of furnace. With a direct fusion type, preheating and cooling can be done so rapidly that this correction does not enter; in fact, this is a part of the regular procedure. If such a radon determination were made simultaneously with a helium determination, the result would be more valuable than determinations made on separate samples as has been done in the past.

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[8] Evans and Goodman: in preparation.

[9] Goodman: (private communication) has found that this is not the case when charcoal is present.

TABLE II.

Comparison of Three Methods of Determining Helium Age.

Method	Rock	He x 10^5 cc. per gm.	Ra x 10^{13} gm. per gm.	Th x 10^6 gm. per gm.	Rate of He production alphas per mg. per hr.	Age, in Million years
Indirect	Quincy riebeckite granite,	3.3 ±0.2	10.9±0.33	7.8±0.57		59±3
Rn, Tn, He	150 ft., Swingle Quarry,	4.8 ±0.4	12.9±0.42	10.2±0.54		69±6
method.	Quincy, Mass.					
		Average for other Quincy samples:				66±2
Radon condensation method.	Same as above.	4.1 ±0.1	12.2±0.4	9.0±0.6		65±7
Direct fusion alpha-count method.	"	4.0*±0.5			1.42±0.08 1.53±0.07	
					Average 1.48±0.08	76±10
"	Same at 600 ft.	4.17±0.12			1.8 ±0.15	68±7

* Average value for large specimen 4.1 x 10^{-5} cc. per gram; average of eight helium determinations on Quincy granite specimens from adjacent quarries 3.9 x 10^{-5} cc. per gram.

The results of a comparison of ages by the three methods are shown in Table II; they are all in substantial agreement.

The general agreement between the different methods is significant in that it indicates the validity of the principles and constants which are involved, and that the result is the true helium index of the age. Whether or not the ages are absolute depends upon the problem of the degree of retention of helium within rock minerals. This question is beyond the scope of this note and is being treated in other papers.

It will be observed that the values obtained by the alpha count method are a little higher, but a recent development[10] has been the discovery that an occasional rock deposit emanates radon, some of which may be lost in the stream of nitrogen which is passed slowly through the chamber. This would give too low a count and too high an age. While this is apparently a rare occurrence, it may explain the results on the Quincy granite. This is suggested by experiments on the separate minerals,[11] and by the fact that the results obtained by the author and Goodman[7] in a large number of age determinations by the radonthoron and alpha count methods were ordinarily in better agreement than the results given in Table II. However, in some specimens the helium content varied by as much as a factor of two, even in the same hand specimen, and in such cases there is the possibility that the age would be off by this factor when separate samples are used, unless the inhomogeneity were detected and a number of analyses made to lower the probable error to a reasonable value.

Experiments on this method are to be resumed within the next year.

The author wishes to acknowledge the Royal Society of Canada for the award of a fellowship in Geological Sciences, and Prof. R. D. Evans and Dr. Wm. D. Urry for the use of their laboratories during the period of tenure.

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[10] Goodman: Private communication.
[11] Keevil: This Journal, in press.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
CAMBRIDGE, MASS.

SCIENTIFIC INTELLIGENCE.

PHYSICS.

Electricity and Magnetism; by S. LEROY BROWN. Pp. v, 310; 126 figs. New York, 1937 (Henry Holt and Co. $2.80).—This is a first text-book for college students in the subject of its title, and is evidently to be used as a one-term course. The book departs from the more usual historical approach to the subject *via* electrostatics and magnetism, and commences with current electricity. The language is straightforward and concise, and in his manner of presentation the author has aimed at clarity rather than rigor. Except for the initial sequence of topics the book is quite conventional in tone. The old units for magnetic quantities are employed. A knowledge of elementary calculus is required though its use is avoided wherever possible. Subject matter in the so-called field of modern physics is confined to brief accounts of thermionic and photoelectric emission and to electric waves. In addition to sets of problems associated with each chapter, there are at the end of the book 67 pages of supplementary problems including objective questions of the completion type.

A. T. WATERMAN.

Kimball's College Physics; by ARTHUR L. KIMBALL. Fifth edition. Revised by Peter I. Wold. Pp. xii, 729; 585 figs. New York, 1937 (Henry Holt and Co., $3.75).—It is a real tribute to a text-book when it undergoes a revision by another than the author and yet retains the original author's name in its title. *College Physics*, by A. L. KIMBALL, was probably the most widely-used college text of the past twenty-five years. After three revisions by Professor Kimball's son, A. L. Kimball, Jr., in which the original book was left almost intact, and supplementary pages added to bring the book up to date, the present fifth edition has been carefully revised and curtailment made in places to allow for new material. Some rearrangement of content has been made, notably in *Sound* and in *Heat*, and much of *Electricity* has been rewritten. This has been done without detracting from the original structure and general tone of the book, which remains clear, teachable and sound.

A. T. WATERMAN.

GEOLOGY.

Geology and Natural Resources of West Virginia; by PAUL H. PRICE, RIETZ C. TUCKER and OSCAR L. HAUGHT. Pp. xi, 462; 61 figs., 231 pls., and map. West Virginia Geological Survey, Vol. X, 1938.—This book was written as a reference and a text for the study of geology in the schools and colleges of West Virginia. The first hundred pages are devoted to a brief description of the State, followed by an outline of geologic processes, including a rather full account of the nature and formation of coal, and an introduction into the principles of stratigraphy and historical geology. The last third of the book is principally an account of the mineral and natural resources of the State from an economic aspect, though this section also includes the thickness of the geologic series by counties.

Being limited to West Virginia, this book omits all but Paleozoic stratigraphy, and contains only brief discussions of igneous and metamorphic rocks. Consequently it has little value as a textbook outside the State. It is profusely illustrated, but the reproduction of the photographs is poor. JEAN BERDAN.

Physiography of Eastern United States; by NEVIN M. FENNEMAN. Pp. xiii, 714; 197 figures, 7 plates. New York and London, 1938 (McGraw-Hill Book Co., $6.50).—This book is a companion volume to the "Physiography of Western United States," published by the same author in 1931, and it thus completes a comprehensive survey of the physiography of the entire country. The new volume is concerned with that portion of the United States east of the Great Plains Province the boundary line of which follows the Balcones escarpment in southern Texas, the "break of the plains" in the Panhandle of Texas, the Red Hills and the Smoky Hills in central Kansas, and the approximate western limit of pleistocene glaciation in central Nebraska and the Dakotas. In the systematic description the author has adopted, with slight revision, the physiographic provinces as set forth by the United States Geological Survey.

Even though a large proportion of the text is devoted to pure description, the fact is fully appreciated that physiography is more than a mere descriptive study, and the attempt is always made to connect the land forms with the underground geology and to interpret the geomorphic history which gave rise to the present day features. In many cases where the problems presented are definitely not settled to everyone's satisfaction, the author desists from making dogmatic statements and frequently leaves the reader with several alternative hypotheses from which to draw his own conclusions. The historical interpretations are of necessity generalized. The attempt has been made to present a broad historical outline or framework for each province into which framework the countless local episodes may be fitted by those who want to go deeper into the history of any one region.

The book embodies few if any new or original ideas, the main part of the material it presents being drawn from a voluminous and widely scattered literature. The chief contribution of this volume is the compilation and organization of this great mass of information into a unified story of the development of the main physiographic features of the Eastern United States.

S. WARREN HOBBS.

Geochemische Verteilungsgesetze der Elemente IX, Die Mengenverhältnisse der Elemente und der Atom-Arten; by V. M. GOLDSCHMIDT. Vid. Akad. Skrifter i. Oslo, I, Mat.-nat. Kl., no. 4; 148 pp., 1938.—In recent years a large amount of work has been done in determining the distribution of the chemical elements in the Earth's crust and in meteorites. Much of it was done under the leadership of V. M. Goldschmidt, but important contributions have also been made by I. and W. Noddack and by G. von Hevesy. The great increase in quantitative data becomes strikingly apparent when the present notable monograph is compared with Clarke and Washington's "The Composition of the Earth's Crust," published in 1924; perhaps equally striking is the change in view point, the result largely of the rapid growth of atomic physics.

As the result of the use of improved chemical methods, of spectrographic and X-ray techniques, and combinations of these methods, quantitative data are now available concerning the distribution of most of the chemical elements, both in the crust and in meteorites. From these figures average contents in the crust are derived as well as in the meteorites, and are compared with the abundance of the same elements in the sun and stars as determined by astrophysical means. Opinions will long diverge on the validity of the methods by which these averages are obtained. At any rate, the abundance of the commoner elements—oxygen, silicon, aluminum, iron—agree remarkably well, whatever method is used, with the figures given by Clarke and Washington in 1924, although the method employed by these authors, as they themselves pointed out, was logically indefensible.

Goldschmidt rightly takes issue with Clarke's concept of a crust 10 miles thick and the calculations based on it, which are taken in many quarters as if they were established facts in geology. He takes issue also with the interesting proposition laid down by I. Noddack in 1936 that all minerals contain all the chemical elements—that is, if the analytical methods used are sufficiently refined all the chemical elements can be found in every mineral. Goldschmidt argues that most of the elements claimed to have been thus found are impurities due to inclusions in the minerals, but despite the force of this objection, much remains to be said for Noddack's argument that the composition of minerals ought to be investigated subjectively, regardless of beliefs as to what elements ought to be present because of isomorphism, ionic radii, or other *a priori* considerations.

As far back as 1926 Goldschmidt's work had shown that the three light elements lithium, beryllium, and boron are relatively extraordinarily rare, and this deficiency in their occurrence was suspected to be due to the instability of their nuclei. This inferred instability has now been established by the experimental researches of nuclear physics. The concluding section of the present paper contains the further development of Goldschmidt's ideas on the relation between the abundance of the elements and atomic structure. ADOLPH KNOPF.

An Introduction to Geology; by A. E. TRUEMAN. Pp. x, 258; 133 figs. London, 1938 (Thomas Murby & Co., 4s.).—This little book is a skillfully written survey of the entire field of geology and is designed for use in the schools of Great Britain. Its sixteen chapters include brief, stimulating discussions of such problems as isostasy and the theory of continental drift, as well as the usual subject matter of physical geology. One chapter is devoted to the geologic history of Great Britain. Emphasis is placed on the useful aspects of the science in terms of common experiences. While the approach to each topic is on a very elementary level, the student is led directly and easily to the critical and significant facts and concepts. To each chapter is appended a few questions, and interesting and helpful "Suggestions for Practical Work."

Illustrations consist entirely of simple diagrams and sketches, of which many are obviously from photographs of localities in the British Isles and western Europe. Although a diagram of the American Niagara region is much over-simplified by presenting a straight and quite un-Niagara-like gorge, American beginners may still make profitable use of this brief text.

CHAUNCEY D. HOLMES.

The Royal Society Expedition to Montserrat, B.W.I. The Volcanic History and Petrology of Montserrat, with Observations on Mt. Pelé, in Martinique; by A. G. MACGREGOR. Philos. Trans., Roy. Soc. London, Ser. B, Biol. Sci., No. 557, Vol. 229, pp. 1-90, 9 pls., 8 text figs., 1938.—This report on the island of Montserrat of the Lesser Antillean arc describes its geology and petrology, and the earthquake and soufrière activity that "caused considerable damage and alarm" in 1934 and 1935. The author spent three months on the island in 1936. He collected some fossil corals and many foraminifers in the Roche Bluff tuffs, and these were named by H. D. Thomas and C. D. Ovey. His conclusion is that the rocks holding these fossils are not older than Miocene in age.

Of the eruptions, MacGregor says that "since late Miocene or early Pliocene times, at least seven distinct series of volcanic eruptions have occurred in Montserrat." The Silver Hill volcano, in the north, is thought to be the oldest center; all the others are believed to have been active in Pleistocene or Recent times, this being proved in three instances by fossil and stratigraphic evidence (p. 82).

The author holds that there is a direct connection between volcanic arcs and tectonic movements. He regards the main volcanic arc of the Lesser Antilles "as built up by eruptions originating near the crest of a submerged tectonic arc of which the history goes back to the time of Laramide orogeny. It is further suggested that the origin of the volcanoes that now form the island festoon is connected with great crustal-warping and block-faulting movements in Miocene and (especially) Pliocene times, and that these earth movements and eruptions correspond to those of the 'Cascadian revolution' of western North America" (p. 5). CHARLES SCHUCHERT.

The West American Cenozoic Echinoidea; by U. S. GRANT IV and LEO G. HERTLEIN. Univ. Calif. Pub. in Math. and Phys. Sci., Vol. 2, pp. vi + 226, 30 pls., 17 text figs., 1938.—This good-looking book brings together all the known Cenozoic species of Echinoidea found in western America. There are 201 species (194 named and 15 new) and 64 genera (3 new). At the end of the volume is a brief outline of the morphology of the Echini, "limited mostly to those parts that are likely to be preserved in the fossil state." There is also an abbreviated glossary. The plates are excellent collotypes.

CHARLES SCHUCHERT.

Two New Echinoidea, Aulechinus and Ectinechinus, and an Adult Plated Holothurian, Eothuria, from the Upper Ordovician of Girvan, Scotland; by E. W. MACBRIDE and W. K. SPENCER. Philos. Trans. Roy. Soc. London, Ser. B, Biol. Sci., No. 588, Vol. 229, pp. 91-136, pls. 10-17, 15 text figs., 1938.—In this memoir we are introduced to some well preserved late Ordovician (Ashgillian) echinoids from Scotland, and also, surprisingly, to the oldest known plated holothurian, which resembles an elongated echinoid. It is now clear that the Echinodermata developed their class and ordinal characteristics quickly during early Ordovician time. This evolution is to be discussed in the near future by Doctor Spencer.

The authors redefine *Aulechinus*, define *Ectinechinus* (new), and redescribe *Myriastiches* of Sollas which turns out to be of the Middle Ordovician and not of the Silurian. Mortensen's classification of the Paleozoic echinids is presented, but no discussion of it is attempted at present. The three genera above mentioned are referred provisionally to the Lepidocentridae. None of these fossils is larger than about 1.25 inches, but they are presented in "full dress" in pen and ink restorations 5 to 6 inches long. *Aulechinus* and *Ectinechinus* (an elongate urchin) have small simple lanterns, composed of jaws and teeth only. The periproct is large, with many plates.

The new order Megalopoda includes the new genus *Eothuria*, with circumoral valves; it also is from the late Ordovician of Scotland. Its ambulacra are broad and curved, its ambulacral pores complex, and there is no differentiation of the podia into buccal tentacles and walking feet.

We congratulate the authors on this pace-making memoir.

CHARLES SCHUCHERT.

Bibliography of West Indian Geology; by L. M. R. RUTTEN. Geog. Geol. Mededeelingen, Min.-Geol. Inst. Rijksuniv. Utrecht, Physiog.-Geol. Reeks, No. 16, pp. vii + 103, 1938.—For seventeen years the author has been collecting bibliographic references to the geology of the West Indian region, and he now cites more than 2,500 such titles. He has ransacked the more important libraries of western Europe and has seen about 90 per cent of the papers cited. There is also an index of the various geographical areas, giving by numbers all the papers and books bearing on each. The work is a very useful one, and a time-saver for all who are working on the natural history of the West Indian region, and we are thankful to the author of it for this help.

CHARLES SCHUCHERT.

My Last Expedition to the Antarctic 1936-1937; With a Review of the Research Work done on the Voyages in 1927-1937; by LARS CHRISTENSEN. Pp. 16, 9 pls., Oslo, 1938.—The whaling shipowner who writes this interesting booklet tells us that he was not content to stay at home but that he has instead made nine trips to the Antarctic during the past ten years, not only to see for himself the whaling grounds south of Africa and Australia, but, on five of the expeditions, to make geographic, oceanographic, and zoologic studies, besides satisfying an inherited love of adventure. He had at his service on the last trip not only three floating whaling stations, but smaller steam ships and a Stinson plane having a radius of about 2,000 km.; and he was accompanied by his wife and daughter.

The five Christensen expeditions have sailed about 65,000 nautical miles, have measured and mapped nearly 4,000 km. of coast line, and have photographed about half of this with a mapping camera. The number of photographs exceeds 2,000, and will, it is hoped, make it possible to construct maps of a strip of coast covering about 80,000 km. Some of the reported "land falls" were found to have melted away. Truly, even in the Antarctic, "things generally go right," as Capt. Mikkelsen says!

CHARLES SCHUCHERT.

Ordovician and Silurian Faunas from Arctic Canada; by CURT TEICHERT. Rept. Fifth Thule Exped. 1921-24. Vol. I, No. 5, 169 pp., 24 pls., geol. map, Copenhagen, 1937.—This report brings much needed light regarding the Silurian (Niagaran, with 35 species) and especially the Ordovician (about Trentonian) in an area lying between 63° and 74° north latitude (Melville Peninsula, King William Land, etc.) Nearly 100 species are discussed or described, 34 of which are new, 27 are old, and the rest are not definitely named. The fauna includes the following new genera: *Sowerbyites* (a brachiopod) and the ostracods *Anisochilina, Monoceratella, Basslerites, Steusloffina,* and *Dihogmochilina.*

CHARLES SCHUCHERT.

MINERALOGY.

Mineral Tables for the Determination of Minerals by Their Physical Properties; by ARTHUR S. EAKLE. Third Edition, revised by ADOLF PABST. Pp. v, 73. New York and London, 1938 (John Wiley & Sons, Inc.; Chapman & Hall, Limited; $1.50).—The determination of minerals by physical properties and the use of determinative tables is common practice in many laboratories, and there are a number of books to effect such determinations. Of those in the English language none is better than the tables originally written by Dr. Eakle. The writer of this review does not give a course which is designed to employ such tables, but he has used Eakle's tables in the past and found them excellent.

The third edition, which brings the tables up to date, is prepared by Dr. Pabst, Dr. Eakle's successor in the Department of Mineralogy at the University of California. Constant use of these tables with large classes at that institution enabled the instructors to detect errors and omissions in the tables so that this edition, which contains descriptions of about 200 minerals, should be extremely accurate.

CHARLES PALACHE.

BOTANY.

Botanical Investigations in the Batchewana Bay Region, Lake Superior; by R. C. HOSIE. Nat. Mus. Canada Bull. No. 88. 152 pp., 30 figs. Ottawa, 1938.—The area covered by this report is representative of a large section of country lying north and east of Lake Superior, the so-called Algoma district, concerning which published botanical data are exceedingly scant. Regarding general vegetation conditions in particular, as distinguished from floristic conditions, accurate information for this region has been practically nil, so that the ecological study of plant communities here presented is of more than ordinary interest. Two climax forest types, namely deciduous and northern coniferous, are recognized and described, each with three constituent associations, together with several "transitional" forest and woodland communities due to fire. Attention is directed to the physiographic and successional relations of various communities. Included also and supplementing the above are a catalogue of the vascular plants, by T. M. C. Taylor, and a study of the mammal population, by C. H. D. Clark.

G. E. NICHOLS.

An Ecological Glossary; by J. RICHARD CARPENTER. Pp. viii, 306. Norman, Oklahoma, 1938 (The University of Oklahoma Press, $4.00).—Someone once described ecology as the science of saying things that everybody knows in terms that nobody can understand. Be that as it may, certain it is that the vocabulary of this comparatively recent branch of biological science has today assumed proportions which at times are bewildering, even to the expert. Under these circumstances there is ample reason for the compilation of a glossary, and the author is to be commended in his effort "to bring together and make available the more technical and restricted uses of the terms which have been and are in ecological literature." Upwards of three thousand terms have been listed and characterized by definition or description, many of them by several or even many definitions, with literature sources specifically cited for the majority. A dozen tables and maps of ecological interest are presented in the appendix.

At first sight the text apparently leaves little to be desired; but closer examination reveals numerous sins of both omission and commission. Various important ecological terms have been left out completely while various of those that are included have been made the victims of gross misstatements of one sort or another. In spite of these discrepancies, however, the book undoubtedly will prove very useful. It is only to be regretted that a work so admirably conceived could not have been executed with an equally admirable degree of completeness and scientific accuracy. Regrettable also, incidentally, is the author's unqualified characterization of ecology, in the preface of the book, as "The science of communities," since it is exceedingly doubtful if this circumscribed use of the term ecology, recently proposed, will ever replace the long-used and widely accepted definition of this subject as the science of organisms in their relation to environment. G. E. NICHOLS.

The Longevity of Plants; by DR. HANS MOLISCH. English edition; by EDMUND H. FULLING. Pp. 226; 38 figs. New York, 1938 (Published by the Translator, $3.00).—In so far as plants are concerned, the original German edition of this work, issued in 1928, represented the first comprehensive survey of this important biological subject to be attempted, and the translator has rendered a service in making the subject-matter of that book more readily available to the English-speaking public. The volume comprises seven chapters, of which the first two present a detailed summary of the more essential facts regarding longevity in various different plants and groups of plants, as set forth in the literature. Chapter three discusses various special phases of the subject, including the longevity of plant organs and tissues. The last four have to do with facts and ideas relating to the means by which life in plants can be prolonged, the phenomena of rejuvenescence and "apparent death" in plants, and the old age, death and "alleged potential perpetual life" of trees. The bibliography of the German edition is supplemented by a list of the more recent literature references on longevity and related subjects.

G. E. NICHOLS.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Astronomy. A Textbook for University and College Students; by ROBERT H. BAKER. Pp. x, 527; 302 figs. Third edition. New York, 1938 (Van Nostrand, $3.75).—During the eight years that have elapsed since its first publication Baker's book has been accepted as an excellent textbook for introductory courses in astronomy. Many professional astronomers have found it useful as a reference book: the statements in the book are reliable and, as a general rule, are the latest word on the subject at the time of publication. The completely revised third edition is not likely to be inferior to its predecessors in these respects. The small number of errors that were noticed in the course of a first reading are excusable in such a thorough revision.

The most important changes are in the four chapters (VIII to XI) that give an account of what may be called the astronomy of the galactic system. This wide and active field with its many sub-divisions and interrelations among individual topics defies almost any attempt at orderly presentation. It is not surprising to see that the author has rearranged and partly rewritten these chapters. He has been particularly successful with the chapter on the structure of the galactic system. The previous editions were liable to create some confusion in the minds of students as to the distinction between the local system and the greater galactic system. By deviating from the historical development, and presenting the greater galactic system first, this objection has been overcome.

Improvements in the earlier sections of the book are better star-charts and more information on the early history of astronomy. Questions and problems are now given at the end of each chapter. The index of names, containing well over three hundred entries, is improved by the addition of biographical details. The list is long because of numerous references to recent contributions to astronomy. This policy enlivens the presentation but has some disadvantages. A student cannot be expected to remember all these names, and he needs some guidance in making his selection of those to which probably more than ephemeral interest is attached. Following a distinctly different policy, a widely-known foreign textbook on astronomy does not quote the name of any living scientist. There must be some middle-of-the-road solution of this problem for writers of textbooks.

DIRK BROUWER.

OBITUARY NOTES.

MR. DARWIN M. ANDREWS, horticulturist of Boulder, Colorado, died on August 14 in his sixty-ninth year.

MR. VICTOR KING CHESNUT, who had been connected with the U. S. Department of Agriculture as botanist and chemist, died on August 9 at the age of seventy-one.

MR. GUY N. COLLINS, chief botanist for the U. S. Department of Agriculture's Bureau of Plant Industry, and who introduced the avocado pear in this country, died on August 14 at his home in Lanham, Md. He had just passed his sixty-sixth birthday. Mr. Collins imported from Mexico the seeds and seedlings of a new type of cotton and introduced the plant to this country. To-day, the great plantations of the Southwest are devoted almost exclusively to this type of cotton or cotton developed from it. For a great part of the last thirty years, Mr. Collins had devoted his time to research in developing corn hybrids and cross breeds.

PROF. LEO FROBENIUS, explorer, author and morphologist, died on August 9 at the age of sixty-five. He was born in Berlin and had often lectured on archaeology before the former Kaiser Wilhelm. Professor Frobenius was a noted ethnologist and was regarded as one of the world's greatest authorities on the art of prehistoric peoples. He led twelve expeditions into Africa.

DR. CHARLES-EDOUARD GUILLAUME, who died recently at the age of seventy-seven, had been the director for fifty-three years of the Bureau International des Poids et Mesures, at Sèvres near Paris, where he carried out his life's work. In 1920 he was awarded the Nobel Prize for Physics for his work on the nickel-iron alloys.

DR. THOMAS CARLISLE HEBB, professor of physics at the University of British Columbia since 1918 and head of the department since 1920, died at Vancouver on August 15 at the age of fifty-nine.

DR. JOHN N. LOWE, associate professor of biology at the Northern State Teachers College at Marquette, Mich., died on July 27 in his fifty-second year.

DR. G. M. JOHNSTONE MACKAY, director of research at the Stamford, Conn., laboratories of the American Cyanamid Company, died on July 29 on his fifty-fifth birthday.

MR. FERDINAND SCHUYLER MATHEWS, illustrator and author of books on art and natural science, died on August 20 at the age of eighty-four. He was a botanical artist on the staff of the Gray Herbarium, of Harvard University. He wrote many volumes about birds, trees and flowers.

DR. FRED CAMPBELL MEIER, extension pathologist of the Office of Coöperative Extension Work investigating diseases of cucurbits, died on July 28 at the age of forty-five. In addition to his work on plant disease control, Meier will be remembered for his work on his hobby, aerobiology. He was intensely interested in the microbial content of the upper air and had spent much money and time devising apparatus, making collections, photographing slides and studying cultures.

Mr. E. M. Nelson, formerly president of the Quekett Microscopical Club and of the Royal Microscopical Society, died on July 20 at the age of eighty-seven.

Nature reports the death of Prof. Nicola Parravano, professor of general chemistry in the University of Rome, aged fifty-five.

PUBLICATIONS RECENTLY RECEIVED.

Plant Physiology; by Nicolai A. Maximov. Second English edition. New York and London, 1938 (McGraw-Hill Book Co., $4.50).

Trees of Northeastern United States. Native and Naturalized; by H. P. Brown. Boston, 1938 (Christopher Publishing House, $3.00).

Rainfall and Tree Growth in the Great Basin; by Ernst Antevs. New York and Washington, 1938 (The Carnegie Institution of Washington and the American Geographical Society of New York, $3.00).

Biochemistry for Medical, Dental and College Students; by B. Harrow. Philadelphia and London, 1938 (W. B. Saunders Company, $3.75).

March of the Iron Men. A Social History of Union Through Invention; by Roger Burlingam. New York and London, 1938 (Charles Scribner's Sons, $3.75).

Textbook of Comparative Physiology; by C. G. Rogers. Second edition. New York and London, 1938 (McGraw-Hill Book Co., $5.00).

The Gold Missus. A Woman Prospector in Sierra Leone; by Katharine Fowler-Lunn. Pp. viii, 303; 33 illus., 4 maps. New York, 1938 (W. W. Norton & Co., $3.00). This book depicts the experiences of Katharine Fowler-Lunn, who went alone on a geological expedition to the Sierra Leone, in West Africa. She ventured deep into the African Jungle. The first time a white woman had ever been in that part of the world, with only natives as guides and servants. The book is vividly written and of intense interest to the layman.

U. S. Geological Survey. Professional Papers as follows: 189-A Species and Genera of Tertiary Noetinae; by F. S. MacNeil. Pp. ii, 39; 6 plates, 2 figs. Price 20 cents. 190. Lower Pliocene Mollusks and Echinoids from the Los Angeles Basin, California; by W. P. Woodring. Pp. ii, 67; 9 plates, 2 figs. Price 30 cents. 189-C. Pliocene Diatoms from the Kettleman Hills, California; by K. E. Lohman. Pp. ii, 102; 4 plates. Price 15 cents. Water-Supply Papers as follows: 810. Surface Water Supply of the United States. 1936, Part 10. The Great Basin. Pp. iv, 90; 1 plate. Price 20 cents. 820. Drought of 1936. With Discussion on the Significance of Drought in Relation to Climate; by J. C. Hoyt. Pp. iv, 62; 2 plates, 18 figs., 10 tables. Price 15 cents. Bulletins as follows: 886-C. Geology and Ore Deposits of the Southwestern Arkansas Quicksilver District; by J. C. Reed and F. G. Wells. Pp. vi, 90; 17 plates, 14 figs. Price 75 cents. 893. Metalliferous Mineral Deposits of the Cascade Range in Oregon; by Eugene Callaghan and A. F. Buddington. Pp. viii, 141; 22 plates, 7 figs. Price $1.25. 900-A. Subsurface Geology and Oil and Gas Resources of Osage County, Oklahoma. Pt. 1. Townships 22 and 23 North Ranges 10 and 11 East; by N. W. Bass, et al. Pp. iv, 45; 1 plate, 1 fig. Price 30 cents.

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THE RADIUM CONTENT OF MARINE SEDIMENTS FROM THE EAST INDIES, THE PHILIPPINES, AND JAPAN, AND OF THE MESOZOIC FOSSIL CLAYS OF THE EAST INDIES.

ROBLEY D. EVANS AND ARTHUR F. KIP.

ABSTRACT.

The mean radium concentration in eleven terrigenous-mud ocean-bottom deposits from the vicinity of the East Indies, the Philippines and Japan is 2.5 x 10^{-12} g Ra per g, or about five to ten times the usual values for sedimentary rocks. The terrestrial occurrences of so-called fossil deep-sea clays on Borneo, Rotti and Timor have a much lower radium concentration than contemporary deep-sea red-clays or even terrigenous muds. These analyses suggest either that radium, not uranium, is primarily precipitated in the ocean-bottom sediments, or that the East Indian fossil deep-sea clays are shallow-water deposits. The geological evidence supporting the abyssal origin of these deposits seems strong enough to warrant the conclusion that the high radium content of fresh deep-sea red clays is mainly due to the precipitation of radium itself, without regard to the oceanographic behavior of uranium.

I. INTRODUCTION.

Considering the vest extent and importance of the ocean-bottom sediments, relatively few radium analyses have been made on these materials. Doubtless this is partly due to the difficulty of obtaining significant specimens for analysis, most of the ocean-bottom materials having been collected with a "snapper" dredge. Piggot, realizing the desirability of core samples of the ocean bottom as a result of his work on the radium content of samples collected by the ship *Carnegie,* has devised an apparatus[1] for securing core samples from any depth. Such extensions of sampling technique may well lead to the solution of many important oceanographic problems.

The radium content of terrestrial materials, particularly from North America, is fairly well known. In general, acid igneous

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rocks contain about 1 x 10^{-12} g radium per g rock, while soil, limestone, sandstone and basalts contain appreciably less radium.[2] It is significant then that the three previous workers[3] on the radium content of deep-sea bottom sediments are in qualitative agreement in assigning a high radium content to the ocean-bottom sediments.

In presenting his own results Piggot[3] has also provided a valuable tabulation of the data of Joly and Pettersson. It is generally agreed that Joly's radium values on all types of specimens are systematically too high.

For important details on the origin and description of the individual specimens, reference can be made to the original papers or to Piggot's summary table. The general trend of the observations is indicated by the following table, which gives only the number of ocean-bottom specimens examined by each worker, and the arithmetic average of his separate radium analyses of these specimens.

TABLE I.

Average radium content of the ocean-bottom sediments, *without regard to the type of deposit*, examined by all workers.

Observer	Number of Specimens	Average Radium Content in 10^{-12} g. Ra Per g.
Joly .... (1908)	12	17.8
Pettersson .... (1930)	28	11.0
Piggot .... (1933)	28	6.5
Evans and Kip....... (1937)	11	2.5

Estimates of the thickness of the deep-sea deposits vary, but Kuenen[4] has recently gathered evidence for a layer of deep-sea deposits five to six kilometers thick on the ocean floor. Even if the sediments are regarded as somewhat thinner than this, they still may represent a large source of thermal energy, due to their radioactivity. They require further and more detailed study of their geophysical significance. Even disregarding radioactive ore deposits, the rocks of the earth contain more than enough uranium and thorium to supply all the energy continuously expended in dynamic geological processes, such as continental drift, mountain building, earthquakes, volcanism and magmatic convection currents in the substratum.[5]

As a large proportion of the earth's surface is ocean, knowledge of the extent and radioactivity of its bottom deposits is of fundamental importance to dynamic geophysics.

II. URANIUM AND RADIUM IN DEEP-SEA DEPOSITS.

It must be emphasized that no *uranium* analyses have ever been made on ocean-bottom materials. In all cases the radium content is determined, by separating and measuring its emanation, radon. The radium content can be accurately determined by this method, but computations of the uranium content are only valid if radioactive equilibrium is present. So far there is no evidence on this point, but direct uranium analyses should soon become possible through extension of the studies by Hernegger and Karlik[6] of the brilliant fluorescence excited by ultra-violet light in sodium fluoride activated with minute traces of uranium.

In the meantime, Piggot[8] has proposed a mechanism for the formation of high radium concentrations in deep-sea deposits. It is first necessary to assume that although radium alone is measured its parent substance, uranium, is present in substantially its equilibrium amount. Chemically, the oxides of uranium, iron and manganese are among the less soluble compounds of these elements. The very deep bottom waters are free from organic material and are oxidizing, as is borne out by the oxygen measurements made during cruise VII of the ship *Carnegie.* Piggot proposes that in this oxidizing environment, the ferro-manganese nodules are formed and the uranium concentration, as computed from the radium content of the bottom sediments, is enhanced.

This elucidation of ocean-bottom chemistry in terms of oxygen content has an attractive simplicity. The present work as well as our previous paper on the radium content of sea water[7] was undertaken mainly to test some of the consequences of Piggot's theory. Enormous complications immediately arise because of our ignorance of the degree of radioactive equilibrium between uranium and radium, not only in the bottom sediments but in the sea water as well. Whether the ultimate source of radium in the sea is mainly in the terrestrial rocks, as Joly[8] thought, or in submarine volcanism as Pettersson[8] suggested, or in ore bodies on the ocean floor as Iimori[8] proposed, we still have no *a priori* method of arriving at a significant estimate of the radium-uranium ratio for ocean water or sediments.

We may reasonably examine the consequences of two extreme assumptions. In both we omit consideration of the thorium series because no successful thorium measurements have yet been made on oceanographic specimens. As one extreme let us assume that uranium plays the dominant rôle in oceanographic radioactive chemistry, and therefore that the radium-uranium ratio in fresh sediments is far below its equilibrium value. At the opposite extreme the rôle of radium would dominate, the radium-uranium ratio being far in excess of the equilibrium value.

Taking uranium as dominant, Piggot's mechanism of uranium oxide precipitation in the oxidizing environment of the great depths of the ocean is readily visualized.

Possibly a plausible mechanism might be devised for the continuous precipitation of uranium from the overlying water, but we will omit this complication here. A freshly deposited layer of bottom mud would then contain much uranium and little radium. If this fresh layer were then isolated, either by being covered over with a new layer or by being removed from the ocean bottom, its radium content should gradually increase with time, due to the formation of radium by the radioactive decay of its parent, uranium. The radium content should continue to rise until it reaches radioactive equilibrium with the uranium.

In the extreme opposite case in which it is assumed that radium alone is precipitated, the radium content of an isolated specimen should decrease exponentially with time, with a half-value time of about 1690 years, falling in several thousand years to zero, or to a low level dictated by the small amount of uranium originally associated with the specimen.

Three possibilities exist for testing these hypotheses. First, the variation in radium content along a core specimen of deep-sea mud (which some think is laid down as slowly[9] as 1 cm. per 1,000 years) will indicate which of these views is to be favored, provided that fluctuations in the rate of deposition of the original uranium (or radium) are not large enough to mask the decay-induced variation. Here the lower layers of the bottom-mud would be regarded as more or less isolated radioactively by the presence of the overlying mud. Some observations of Pettersson's[8] were made on core specimens. The values tabulated by Piggot[8] as "location or type not given" are listed in Pettersson's Swedish publication as being made along core specimens whose upper-surface value is given in

Piggot's table. These core values are reproduced in Table II. All the core specimens were taken from the ship *Princess Alice*, at her stations given in the first column. In the sixth column is given the depth below the surface of the deposit from which the specimen for radium analysis was taken.

TABLE II.

Variation of Radium Content Along Core Specimens of Ocean-Bottom Sediments. (Pettersson.)

Station	Latitude	Longitude	Depth meters	Sediment	Depth from surface of deposit	Ra content in 10^{-12} g. Ra per g.
2081	26° 37′ N	36° 35′ W	5382	red clay	2 cm.	9.3
"	"	"	"	" "	7 cm.	8.9
"	"	"	"	" "	17 cm.	4.4
1798	32° 18′ N	23° 58′ W	5422	globigerina	2 cm.	1.4
"	"	"	"	ooze	14 cm.	2.2
"	"	"	"		23.5 cm.	3.9
1160	14° 00′ N	30° 01′ W	5443	red clay	8 cm.	3.7
"	"	"	"	" "	14 cm.	4.3
2075	25° 57′ N	35° 08′ W	5580	red clay	2 cm.	8.5
"	"	"	"	" "	14.5 cm.	6.7
2868	43° 05′ N	19° 41′ W	5940	globigerina	2 cm.	3.3
"	"	"	"	ooze	18 cm.	3.0
1169	12° 05′ N	33° 31′ W	6035	red clay	12.5 cm.	7.8
"	"	"	"	" "	18.5 cm.	30.3

Radium analyses at three depths were made on only two of the cores of Table II. One of these cores shows a decrease in radium content with age (depth), while the other shows an increase. No definite conclusion can be drawn from these or the remaining four cores, of which two show an increase and two a decrease in radium concentration with age. The lack of a uniform tendency may be real, indicating that the radium-uranium ratio varies from place to place, or the expected variations may be masked by real fluctuations in the rate of deposition of radium (or uranium), or uncertainties in the analytical methods may account for some of the trends.

Secondly, Kurbatov[10] has recently made radium analyses of nine ferro-manganese deposits from the seas and lakes of the U.S.S.R., finding an arithmetic average of 10.9×10^{-12} g. Ra per g. Chemical analysis showed the constancy of chemical composition from the center to the outer edge of a disk-shaped ferro-manganese concentration from 58 meters depth in the Kara Sea. The radium content at the center, however, was only 16 per cent of that in the outer layers, while the middle third showed 63 per cent of the radium content of the outer third. This lower radium content of the older (inner) portions of the concretion suggests that the original radioactive substance precipitated in this case was radium, not uranium. On this assumption Kurbatov computes the age of the concretion to be about 5,500 years. A second concretion from Lake Uksche, Karelia, is also poorer in radium in the center.

Finally, there are a few terrestrial deposits in both the East and West Indies which certain geologists have identified as "fossil deep sea clays." If these are truly materials laid down in the depths of the ocean and later lifted above the surface of the ocean then they would represent nearly ideal material for testing the uranium precipitation hypothesis. Their isolation from their place of origin would have been complete for many thousands of years, and a high radium content would have been maintained only if the original material contained a correspondingly large amount of uranium. Fossil deep-sea clays from the East Indies, as well as contemporary deep-sea clays from the same and other areas, have been analyzed for radium as described in the next section.

III. ANALYTICAL METHODS.

The analytical technique developed for the radium analysis of geological and other specimens has been completely described[11] by one of us. The marine specimens were weighed and preheated to 1,000° C. to drive off carbonates. Each was then sealed in a glass tube for at least one month to reëstablish the radium-radon equilibrium. All of the radon was then released from the specimen by direct fusion at about 2,000° C., and the free radon representing the cold emanating power of the specimen combined with this radon. Photographically recorded electrometer readings were then taken of the ionization current produced in the double ionization chamber system by the alpha rays of the released radon and its decay products.

By comparison with the ionization produced by the radon from a known amount of radium, the radium concentration of the original specimen is readily computed. The radium standard solution is a subdilution of a quantity of radium which had been directly compared with the International Radium Standard.

It should be mentioned that much of the uncertainty in the geophysical interpretation of the radium analyses of rocks, deep-sea muds and other materials arises from uncertainties or systematic errors in the analyses. In an effort to locate the causes of these errors and to correct some of the published data on geophysical radioactivity, one of us is sponsoring a general program of interchecking among the active research workers in these fields. The program is now entering its third year and it is hoped that all the participating laboratories may finish their analyses of the set of standard specimens in the near future.

IV. ANALYTICAL RESULTS.

The first suite of specimens examined was collected in the Sea of Japan, which separates Japan from the mainland of Asia, and in the Pacific Ocean east of Japan. Ten specimens were obtained from the Hydrographic Department of the Imperial Japanese Navy through the coöperation of Rear Admiral Yaiti Ono. Four of these specimens weighed only one gram each and were therefore not analyzed. The remaining six samples, having a slightly greater weight, were chosen for radium analysis. Table III presents the important data on these specimens, together with the results of our radium analyses.

The specimens were examined microscopically by Prof. A. Pabst and Dr. P. D. Trask. Radiolarian fragments were found in specimens J5, 7, and 9, while all contain feldspar and glass and are to be classed as *terrigenous muds*.

Piggot[8] analyzed three terrigenous muds (taken by the *Carnegie* at its stations 113, 115, 116) from the same general area east of Japan. He obtained entirely comparable results,* the individual values being 1.88, 4.12 and 4.76 x 10^{-12} g. Ra per g.

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* The highest radium concentrations are usually found in the red clays, and these bring up the general averages of the other observers, as given in Table I. Piggot's average value for 13 red clays is 9.5 x 10^{-12} g. Ra per g.

In Section II we pointed out the possibility of making a critical test of the uranium precipitation hypothesis by analyzing fossil deep-sea clays for radium. High values, comparable with the values for contemporary deep-sea clays, would substantiate the hypothesis. Unfortunately, all geologists are not in agreement as to the existence of such deposits. However, it seems agreed that if any fossil deep-sea clays do exist, they are the red clay-shales found in the East Indian Archipelago, notably in the islands of Timor, Rotti and Borneo. Similar deposits are also found in the West Indies on Barbados. The Netherland's geologists and oceanographers who have worked with the East Indian deposits seem unanimous in the conviction that these now terrestrial occurrences were originally laid down at great depths in the ocean. In nearly every respect these "fossil" red clays resemble the contemporaneous deep-sea red clays.[12] The chemical compositions of the two are very similar, both contain ferro-manganese nodules (concretions) having similar chemical compositions, and both contain sharks' teeth. In both the contemporary and fossil deposits the sharks' teeth consist

TABLE III.

Radium Content of Ocean-Bottom Sediments from the Pacific Ocean East of Japan (J1 to J7), and from the Sea of Japan (J8 and J9).

Specimen	Collecting vessel	Latitude	Longitude	Depth meters	Radium concentration in 10^{-12} g. Ra per g.
J1	Mansyu	27° 08′ N	135° 37′ E	4412	3.63 ± 0.04
J3	Mansyu	30° 09′ N	146° 55′ E	6231	4.74 ± 0.05
J5	Mansyu	34° 25′ N	140° 10′ E	2615	1.26 ± 0.02
J7	Mansyu	38° 16′ N	150° 02′ E	6087	2.87 ± 0.03
		Ocean side, arithmetic average			3.12
J8	Yamato	39° 42.5′ N	135° 40.8′ E	1113	2.53 ± 0.03
J9	Yamato	40° 24′ N	139° 15′ E	2030	1.30 ± 0.04
		Sea of Japan, arithmetic average			1.91

mainly of fragments, only the enamel of the crown of the tooth remaining, the dentine having been dissolved. Paleontologically the teeth in the fossil clays indicate a Mesozoic age, probably of Upper Cretaceous in Timor, and Jurassic in Rotti and Borneo. It is particularly significant that the calcium content of the fossil red-clay is very low (about one per cent as CaO). Due to the solvent action of sea water the shells of pelagic foraminifera are dissolved during their fall from the surface to the bottom of very deep oceans, and it is a general oceanographic rule that far from land, in deep water, the amount of calcium carbonate in the sediments decreases with the increase of depth.

TABLE IV.

Chemical Analyses of Recent Red Deep-Sea Clays and of the Noil Tobee Red Clay.

Constituents, as oxides	A	B	C
SiO_2	56.12	54.48	61.3
TiO_2	2.01	0.98	0.7
Al_2O_3	14.3	15.94	20.4
Fe_2O_3	10.94	8.66	7.6
FeO		0.84	...
MnO_2	1.62	1.21	trace
CaO	1.65	1.96	1.3
MgO	1.43	3.31	1.5
K_2O	1.95	2.85	trace
Na_2O	3.34	2.05	2.5
H_2O after drying at 100° C.	6.92	7.04	4.3
	100.3	99.3	99.6

A. Recent red deep-sea clays, collected by the *Challenger* in the Pacific Ocean, station 256, 30° 22′ N. Lat. and 154° 56′ W. Long. Depth 5310 meters. Anal. by Harrison and Williams.[12]

B. Average composition of 51 samples of recent deep-sea clay. Anal., G. Steiger.[12]

C. Cretaceous red clay of Noil Tobee. Anal., H. ter Meulen.[12]

Through the generosity of Dr. Ph. H. Kuenen, of Groningen, Prof. G. A. F. Molengraaff and Dr. P. Kruizinga, of

Delft, Holland, who supplied the specimens, we have been able to make a number of radium analyses on these Mesozoic deposits from the East Indies as well as on several fresh deep-sea deposits.

Geologically the most completely studied fossil deep-sea clay formation is that of the Noil Tobee, on the island of Timor, in the Netherland East Indies at about Latitude 10° S, Longitude 124° E. The Noil Tobee is a small river rising about 4.5 km. E.N.E. of the village of Niki-Niki in the district of Amanuban in West Central Timor. In the bed of a little brook joining the right bank of the Noil Tobee, at an elevation of about 480 m above the sea level, the late Prof. H. G. Jonker discovered in 1916 the fossil red clays which have since been studied by Molengraaff, Kuenen, and others.

TABLE V.

Chemical Analyses[12] of Manganese Nodules Found in Red Clay by the Challenger, and of a Manganese Nodule in the Red Clay of Noil Tobee.

	Challenger Stations				
Location	160	252	276	286	Noil Tobee
Depth in meters	4760	5020	4300	4270	
SiO_2	21.80	27.62	13.66	20.01	26.5
Al_2O_3	22.30	6.60	3.10	2.81	10.6
Fe_2O_3		17.82	46.40	17.88	27.7
MnO_2	39.32	25.48	14.82	38.15	18.3
CaO	2.21	2.91	3.53	3.58	1.63
MgO	0.89	1.27	0.74	0.33	0.37
H_2O escaping above 110° C.	11.	15.20	14.40	11.35	11.1
Totals	97.5	96.9	96.6	94.1	96.4

The identification of this clay as a former deep-sea deposit rests jointly on the near absence of detrital minerals, on the paleontological evidence of the sharks' teeth mentioned above, and on the chemical analysis of the clay and the manganese nodules which it contains. In Tables IV and V we reproduce[12] chemical analyses typical of some of the Noil Tobee materials examined for radium content, and, for comparison, the analysis of contemporary deep-sea red clays and manganese nodules.

TABLE VIa.

Radium Content of Noil Tobee Clays, East Indian and Philippine Ocean-Bottom Sediments.

Sample No.		Depth in Meters	Location	Latitude	Longitude	Ra Concentration in 10^{-12} g. Ra per g.
Evans and Kip	Kuenen					
(K1)	325		Noil Tobee			0.26 ± 0.04
(K2)	327		Noil Tobee			0.58 ± 0.02
(K4)	331	5050	Banda Sea	3° 34′ S	124° 21′ S	2.36 ± 0.03
(K5)	303	4450	Celebes Sea	4° 53′ N	121° 31′ E	2.81 ± 0.05
(K6)	301	5200	Celebes Sea	4° 48′ N	124° 16′ E	2.73 ± 0.06
(K7)	262	10,050	Mindanao Deep	9° 40′ N	126° 51′ E	1.38 ± 0.02
(K8)	265	4950	Mindanao Deep	6° 12′ N	126° 56′ E	1.76 ± 0.02

Description of Specimens:

(K1) 325. Upper Cretaceous (fossil) red clay from Noil Tobee, Niki-Niki, Timor. Red layer at the bottom of the deposit. The larger manganese nodules occur in this layer.

(K2) 327. Upper Cretaceous (fossil) brown clay from Noil Tobee, Niki-Niki, Timor. Brown upper layer containing small squashed nodules.

(K4) 331. Mixture of top and bottom of a 187 cm. long core of decalcified deep-sea ooze. Appearance and composition much like (K5) 303, but with fewer organic remains.

(K5) 303. Partly decalcified deep-sea ooze. Greyish clay, containing foraminifera, siliceous remains of organisms (sponge spicules and radiolaria) and rounded grains of quartz and feldspar, very few femic minerals.

(K6) 301. Volcanic-mud deep-sea ooze. Brownish clay, containing foraminifera and idiomorphic minerals of volcanic origin (pyroxene and amphibole).

(K7) 262 Brownish red clay, containing little else than fine mineral particles, partly of volcanic origin.

(K8) 265. Brownish red clay, similar to (K7) 262 but with more and larger mineral particles and some foraminifera.

The chemical similarities, on which the claims for these fossil deposits rest, are apparent.

Table VIa shows the results of our radium analyses of two typical specimens of the Noil Tobee clays, and of five recently collected ocean-bottom deposits from the East Indian and Philippine region. All these specimens, the descriptive notes and the mechanical analyses were kindly supplied by Dr. Ph. H. Kuenen of the Geologisch Instituut der Rijksuniversiteit in Groningen, Holland.

TABLE VIb.

Mechanical Analyses and $CaCO_3$ Content of the Contemporary Ocean-Bottom Sediments of Table VIa. (Kuenen.)

Particle Size	Per Cent.					
	(K4) 331 top	(K4) 331 bottom	(K5) 303	(K6) 301 top	(K7) 262	(K8) 265
<0.5 μ	5.51	4.93	7.90	7.12	12.65	6.14
0.5 to 2 μ	14.24	12.60	16.30	9.55	16.36	6.97
2 to 5 μ	24.34	32.95	29.40	23.49	27.72	10.70
5 to 20 μ	34.38	24.62	16.78	21.83	19.56	9.38
20-50 μ	15.33	17.65	17.06	23.91	21.47	20.52
0.05 to 0.1 mm.	3.20	4.21	8.57	12.15	2.64	26.48
0.1 to 0.2 mm.	1.78	1.97	3.21	1.66	0.37	12.36
0.2 to 0.5 mm.	0.63	0.27	0.90	1.03	0.22	7.67
0.5 to 1 mm.	0.16	0.31	....	0.04	....	0.30
1 to 2 mm.	....	....	....	....	....	0.02
% $CaCO_3$	0.7	2.6	12.12	16.6	1.57	1.77

Dr. Kruizinga, of the Technische Hoogeschool, Delft Holland generously furnished a number of specimens from the fossil clay collections of Professor Molengraaff. The radium content observed in the six most homogenous of these specimens is shown in Table VII. Detailed technical descriptions of these materials could not be obtained.

Except for M12, all the specimens of Table VII were thought to be of abyssal origin. Professor Molengraaff feels that the geological evidence for the abyssal origin of the Borneo specimen, M13, is particularly strong. On the other hand the marl from Soealain, Rotti (M12) is probably not abyssal because of its high lime content, as indicated by the presence of

Belemnites. Thin sections of this specimen indicated that the manganese nodules result from later replacement of the rock by oxides of manganese.

TABLE VII.

Radium Content of East Indian Clays.

Number	Location	Type	Description	Ra concentration in 10^{-12} g. Ra per g.
(M2)	Noil Tobee Timor	Abyssal clay	Glossy dark grey with manganese nodules	3.56 ± 0.03
(M16)	Noil Tobee Timor	Manganese Nodule	Black Fragments	1.63 ± 0.04
(M5) Series 2 No. 368	Nimassi Canon Timor	Radiolarite	Red, very Homogenous	0.19 ± 0.01
(M7) Series 2 No. 112	Near Atapoepoe Timor	Radiolarite	Creamy pink, Homogenous	0.28 ± 0.07
(M12) Series 8 No. 375	Soealain, Rotti	Marl	Silica Marl with Belemnites and manganese nodules. Sample white-grey	0.06 ± 0.02
(M13) Series 2 No. 123	Borneo. 1 km. upstream from NaTandijan,near Kapoeas river. (About 1° N. Lat., 144° E. Long.)	Radiolarite	Very dark red-brown	0.21 ± 0.01

V. DISCUSSION.

The fossil manganese nodule from Timor (Table VII, M16) contains much less radium than has been reported by other workers[8,8] for contemporary deep-sea manganese nodules. For example Piggot[3] found 12.0 x 10^{-12} g. Ra per g. in a manganese nodule from the *Carnegie's* station 151.

The red clay in which the latter nodule was found contained[3] 21.40 x 10^{-12} g. Ra per g., which is nearly twice as much as the nodule itself. This relationship is also evident in the Timor specimen, the clay matrix (Table VII, M2) containing about twice as much radium as the nodules. If iron, manganese and uranium are being simultaneously precipitated by oxidation in the ocean deeps, it seems somewhat surprising that the radioactive substances would favor the clay matrix over the manganese nodule.

The Noil Tobee clays of Table VI are presumably representative of the main body of the deposit, and correspond to the chemical composition of Table IV. These clays are extremely poor in radium, containing only three to six per cent of the average radium content (9.5×10^{-12}) found by Piggot[8] in 13 deep-sea red clays.

Moreover, the remaining four fossil clays (Table VII, M5, 7, 12, 13) are even poorer in radium, and bear no radioactive resemblance to contemporary ocean deposits, even those formed near shore in relatively shallow water.[7]

The deep-sea deposits (Table VI, K4, 5, 6, 7, 8) probably belong to the general class of terrigenous muds, in agreement with Murray's classification of the ocean-bottom deposits of this area. This is in agreement with the radium concentrations observed, which are in general consonance with those for the Japanese area (Table III), and with Piggot's terrigenous mud observations. It should be noted that even in the Mindanao deep of the Philippines (Table VI, K7, 8) the radium concentrations are much lower than for deep-sea red clay deposits, in spite of the vastly greater depth from which the sample K7 was taken. This emphasizes the conclusion that both deep water and quiet water, far from land, are required to produce ocean-bottom sediments of high radium content. Admixture of the Mindanao bottom sediments with terrestrial detritus is indicated by the low radium values for these specimens. We have shown elsewhere[7] that the radium is mainly concentrated in the finest particles of a terrigenous bottom mud, the coarse material being similar in radioactivity to terrestrial geological materials.

The arithmetic average radium content of the eleven terrigenous muds examined (Tables II, VI, VII) is 2.5×10^{-12} g. Ra per g.

We pointed out in Section II that a high radium content in the fossil red-clays would simultaneously support (a) Piggot's proposal that the primary radioactive process in deep-sea clays is the precipitation of uranium by oxidization, and (b) that the terrestrial East-Indian deposits were, in fact, originally laid down as red clays in a very deep ocean. As the radium values are exceptionally low, we must conclude that at least one of these two conditions is not fulfilled. Both cannot be simultaneously true, unless we make an additional *ad hoc* assumption describing an increase in radioactivity of fresh ocean sediments by a factor of about twenty since the Mesozoic era. Pettersson's results on core specimens (See Section II) do not support such an assumption.

No alternative to the abyssal origin of the Noil Tobee red clays has ever been suggested. The absence of dentine in the shark's teeth, the absence of detrital minerals, the presence of manganese nodules, and the chemical composition of these red-clays all point to an abyssal origin. The vertical displacement of several thousand meters required to bring these ancient deposits above sea level is also conceivable. The Alps were uplifted and moved several hundred miles from the Mediterranean during or after the Tertiary. The Timor region suffered considerable diastrophism during the Tertiary, and there is geological evidence for an uplift of about 1200 meters since then. Also the work of Vening Meinesy, Molengraaff, Wanner and others shows that Timor now lies on an active orogenetic zone.

If we accept this body of evidence, then the low values of the radium concentration in the materials studied supports the view that radium precipitation is the more basic mechanism of oceanographic radiochemistry. The radium analyses are not compatible with the view that uranium precipitation is responsible for the high radium content of contemporary deep-sea red clays. The oxidizing environment of the bottom of the ocean should be favorable to the precipitation of radium.

Other arguments in favor of the radium precipitation hypothesis also exist. The accurate analysis of the radium content of sea water shows a marked increase in radium concentration with depth in the water,[7] suggesting that radium is being precipitated and deposited in the bottom sediments. However, these measurements have not been extended to the red-clay areas of the open ocean, and little is known about the accompanying uranium content of the water. Moreover, the reported decrease in radium content toward the center of shallow water manganese nodules (Section II) suggests that radium rather than uranium precipitation is the primary process there involved.

We hope to obtain further evidence on the relative importance of radium and uranium from experiments now in progress on manganese nodules from Noil Tobee and from contemporary red-clay oceanic deposits. The radial gradient of radium concentration in these nodules is being studied at the Massachusetts Institute of Technology. This gradient bears strongly on the radium precipitation hypothesis, as explained in Section II. In certain saline deposits, helium anomolies[18] due to the decay of precipitated radium may also have a direct bearing on this hypothesis.

The radium analyses here reported were made during the spring and summer of 1934 at the University of California during the National Research Fellowship tenure of one of us (R.D.E.). The cordial support of Prof. L. B. Loeb, Dr. T. Wayland Vaughan and other members of the University faculty is gratefully remembered. Dr. Ph. H. Kuenen, of Groningen, and Prof. R. R. Shrock, of the Massachusetts Institute of Technology have been helpful in discussing the geological evidence on the specimens from the East Indies.

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A MIDDLE ORDOVICIAN FAUNA FROM THE VENEZUELAN ANDES.[1]

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ABSTRACT.

A fauna of five species, three new, recently discovered in the Caparro-Bellavista Series in the Venezuelan Andes of South America is described and the age of the series is shown to be Middle Ordovician.

In 1927 Peter Christ[2] recorded the occurrence of a series of Lower Paleozoic schists in the Venezuelan Andes of South America which he named the Caparro-Bellavista series. The relationship of the Caparro-Bellavista to the overlying and underlying formations as established by Christ along the trail from Mucuchachi to Santa Barbara is as follows:

Middle Tertiary	Santa Barbara Series
Unconformity	
Lower Cretaceous	Lomita Series
Unconformity	
Carboniferous	Palmarito Series
Unconformity	
Devonian	Mucupati Series
Unconformity	
Lower Paleozoic	Caparro-Bellavista Series
Unconformity	
Pre-Cambrian	Mucuchachi Series

The Mucuchachi is separated from the Caparro-Bellavista by a major unconformity and forms part of the basement complex of the Venezuelan Andes. On the basis of *Fenestella*, *Productus*, gastropods, brachiopods, trilobites and other groups not mentioned, Christ assigned a Carboniferous age to the Palmarito. He, however, does not give any evidence for his age determination of the Mucupati as Devonian and the Caparro-Bellavista as Lower Paleozoic and as pointed out by Engleman,[3] the ages of the divisions below the Palmarito seem

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[1] Schuchert, C.: Advance notice in "Historical Geology of the Antillean-Caribbean Region," pp. 692-694, 1935.

[2] Christ, Peter: "La Coupe geologique le long du chemin de Mucuchachi a Santa Barbara dans les Andes venezueliennes." Ecologae Geologica Levetiae, August 1927. Abstracted by C. C. Zimmerman in Amer. Assoc. Petrol. Geol., Bull., Vol. 12, pp. 1123-1125, 1928.

[3] Engleman, R.: "Geology of the Venezuelan Andes," Amer. Assoc. Petrol. Geol., Bull., Vol. 19, p. 776, 1935.

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to have been established on the presence of unconformities rather than fossil evidence. Strata of Middle Devonian age, however, do occur on the north flank of the Venezuelan Andes but it is not within the scope of this article to discuss their possible relation to the Mucupati series.[4]

Recently R. A. Terry discovered fossils in strata of Caparro-Bellavista age. Through the courtesy of the Sinclair Exploration Company with which Mr. Terry is associated, the fossils were deposited in Peabody Museum of Natural History, Yale University, under the care of Professor Schuchert. The collection of fossils was made available for study by the writer through the kindness of Professor Dunbar and Professor Schuchert. The writer is indebted to Professor Schuchert for the opportunity to study and describe the fossils of this remarkable find.

The Caparro-Bellavista series is described as being a series of schists varying from sandy and micaeous types to argillaceous, quartzite schists, and it is surprising that Terry was able to find fossils in so metamorphosed a formation. A soft, greyish-white, silty shale which weathers pale reddish-yellow due to iron staining carries the fossils and apparently represents a part of the series which did not undergo much metamorphism.

The collection was made in the first hill outside the Caparro River floodplain, about three-quarters of a mile south of the river, along the trail between Santa Barbara (State of Zamora) and Mucuchachi (State of Mérida). The find is important, for it was along this same trail that Christ worked out the stratigraphic sequence given above and since the fossils were found by Terry in the type locality they can be used to establish definitely the age of the series, or at least that part containing the fossils, for the series was estimated by Christ to be 9,750 feet thick.

The following fossils have been identified in the collection:

Dicranograptus caparroensis n. sp.
Cryptolithus terryi n. sp.
Orthoid(?) brachiopod.
Allonychia(?) *brevirostris* n. sp.
Undetermined pelecypod.

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[4] Schuchert, C.: "Historical Geology of the Antillean-Caribbean Region," p. 692, 1935.

This is not a large fauna but the occurrence of such diagnostic forms as *Dicranograptus* and *Cryptolithus* is sufficient to place the Caparro-Bellavista as Ordovician and thus confirm Christ's Lower Paleozoic correlation of the series. The new species of *Dicranograptus* is similar to *D. ramosus* (Hall) which occurs in the Normanskill of North America. In Great Britain, however, *D. ramosus* (Hall) occurs not only in the Normanskill equivalent, the Glenkiln, but also in the next formation higher up, namely the Lower Hartfell. On this basis, therefore, the Caparro-Bellavista series is believed to represent Normanskill-Glenkiln-Lower Hartfell time.

DESCRIPTIVE PALEONTOLOGY.

GRAPTOLOIDEA

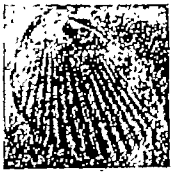
Dicranograptus caparroensis n. sp.

Plate—Figs. 8-9.

Two incompletely preserved specimens form the basis for the description of this new species. One specimen is partly an internal mold with fragments of the thecal walls adhering to it and the other appears to be an external mold. In the latter the outline of the rhabdosome is preserved but very little of the detail can be determined.

The rhabdosome consists of a long biserial portion, of which only 17 mm. are preserved in the one specimen and 13 mm. in the other, and two uniserial branches in which the greatest length preserved is 25 mm. The uniserial branches form an angle of 30 degrees at the axil and this amount, about 8 mm. above the axil, is reduced to 22 degrees in the one specimen and 24 degrees in the other. The reduction may, however, be due to accidental twisting of the branches during preservation. At the axil in both specimens the width of the biserial portion is 2.5 mm. and proximally this width decreases to 2 mm. in the one specimen and slightly under 1.5 mm. in the other. The width of the uniserial branch is 1 mm. at the axil and there is only a very slight increase in width distally.

In the biserial portion of the rhabdosome, where observed, the thecae number 13 in 13 mm. and the two rows of thecae are separated by a zig-zag septum. The suture of this septum is not preserved. The thecae grow in an alternate arrangement. The thecae are 2 mm. long and overlap about one-half of their length. The ventral wall of the thecae forms a gentle sigmoidal curve and the rounded apertural excavation, restricted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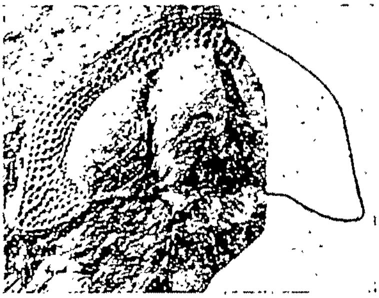
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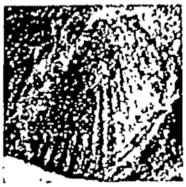
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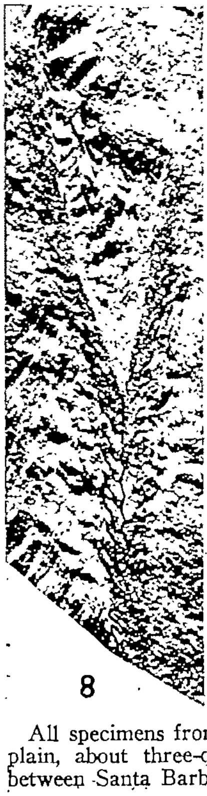
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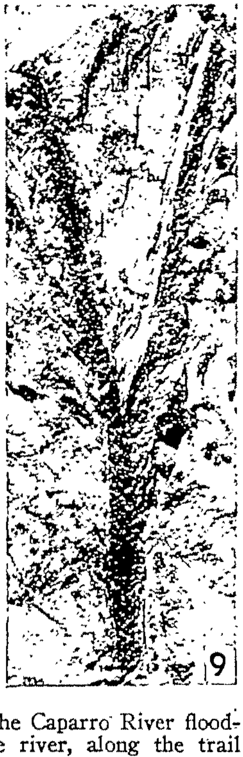
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All specimens from one locality, first hill outside the Caparro River flood-plain, about three-quarters of a mile south of the river, along the trail between Santa Barbara and Mucuchachi, Venezuelan Andes.

Figs. 1, 3-4. *Allonychia ? brevirostris* n. sp. Left valve, right valve and posterior view of left valve. Cotypes Cat. No. 15316 Y.P.M., Figs. 1 and 4, x 2. Fig. 3, x 3.

Fig. 2. *Cryptolithus terryi* n. sp. Cephalon. Holotype Cat. No. 15317 Y.P.M. x 2.

Figs. 5-6. Molds of an orthoid (?) brachiopod. Cat. No. 15318 Y.P.M. x 2.

Fig. 7. Pelecypod, genus and species indet. Cat. No. 15319 Y.P.M. x 2.

Figs. 8-9. *Dicranograptus caparroensis* n. sp. Cotypes. Cat. No. 15320 Y.P.M. Fig. 8, x 3 (retouched), Fig. 9, x 2.

apparently by introversion of the aperture, occupies about one-third the width of the branch. In the uniserial portion of the branch five thecae were observed in a distance of 5 mm.

This species is undoubtedly related to *D. ramosus* (Hall) but differs from it in several features which are believed valid for a specific separation. In *D. caparroensis* the biserial portion is wider, the ventral wall of the theca is sigmoidally curved rather than being gently convex and the angle at the axil is less, being 30 degrees as compared to 40 degrees in *D. ramosus*. According to Ruedemann the maximum length ever reached by the biserial portion of *D. ramosus* is 15 mm. and in the one specimen of this new species the biserial portion is 17 mm. The specimens, however, are not complete at the proximal end and so no comparison as to length can be made with *D. ramosus* var. *longicaulis* Elles and Wood, a variety which has as its distinctive feature a longer biserial portion than the species.

TRILOBITA.

Cryptolithus terryi n. sp.

Plate—Fig. 2.

The description of this new species is based on the internal mold of one specimen consisting only of a cephalon which lacks part of the right side. The left side is used to reconstruct the outline of the cephalon.

The cephalon is wider than long and is approximately semicircular in outline. Both the glabella and cheek lobes are elevated above the fringe and curve downwards convexly to meet it, except at the postero-lateral angle of the cheek where the fringe cuts away part of this angle and is deflected upwards to form a continuation of the cheek. The cheek lobes are flat in the postero-medial area. No eyes or facial sutures are present.

The glabella is slightly elevated above the cheek lobes and lacks the glabellar furrows. It is blunt, club-like in outline with the greatest width at the rounded anterior end. The occipital furrow constricts the glabella posteriorly and the narrow occipital ring bears a long, posteriorly directed spine.

Two antennuary pits are present at the anterior end of each axial furrow between the glabella and the cheek lobe.

The fringe is a prominent feature of the cephalon. It is slightly narrower in front than in the postero-lateral portion and is widest in the genal area. A portion of the fringe extends beyond the posterior border of the cheek lobe and the posterior margin of the fringe is slightly curved. The genal spine is not present on the side preserved. These spines may not have been developed in this species or perhaps due to the non-preservation they are lacking from the specimen. Numerous pits occur in the fringe. Five concentric rows are present in the front and seven in the lateral portion. A radial arrangement of the pits is more noticeable in front than in the lateral portion. Where the fringe is deflected upwards the pits are not regularly arranged except for a row of fine pits paralleling the posterior margin. The pits increase in size away from the cheek lobe except those in the outer row which are approximately the same size as those close to the cheek lobes.

The cephalon of *C. caractaci* (Murchison) from the Caradoc of England resembles the cephalon of *C. terryi* but differs in that the width as compared to the length is proportionately greater, the fringe is larger especially along the anterior part of the cephalon, the pits are larger and further apart, and it lacks the occipital-ring spine. The wood-cut illustrations of *C. caractaci* in Murchison's *Siluria* do not show the occipital ring or the antennuary pits which occur in *C terryi*, but this may be due to the nature of the illustrations. Genal spines are present in *C. caractaci* but, as noted above, may be lacking in *C. terryi.*

Dimensions:

Length of cephalon	12.5 mm.
Width of cephalon at the mid-traverse line . . (estimated)	24 mm.
Length of glabella	9 mm.
Width of glabella at the anterior end	4.5 mm.
Width of glabella at the posterior end	2.5 mm.
Length of occipital ring and spine	6.5 mm.
Length of occipital ring (approximate)	1 mm.
Width of fringe at anterior margin	2.5 mm.
Width of fringe at mid-transverse line	3 mm.
Width of fringe at posterior margin	6 mm.

This new species is named for R. A. Terry who made the remarkable find in the Caparro-Bellavista series.

BRACHIOPODA.

Genus and Species Indet.

Plate—Figs. 5-6.

Two imperfectly preserved molds of a brachiopod in the collection with a semicircular outline and multicostellate ornamentation suggest an orthoid type of test. The length is 4.5 mm. and the width 8 mm.

PELECYPODA.

Allonychia? brevirostris n. sp.

Plate—Figs. 1, 3-4.

Internal molds of a right valve and a left valve of different individuals in the collection are doubtfully referred to *Allonychia* as a new species. In several respects the characters suggest this genus but the hinge structures are not well preserved and until better material is available, this new species, which may represent a new genus, will have to be provisionally placed with *Allonychia.*

The valves are obliquely ovate with the greatest length near the rounded ventral margin and the height is equal to or slightly greater than the length. The valves are moderately convex and although they are from different individuals and are different in size it seems apparent that the species was equivalved. On the posterior part of the mold there is a slightly concave and smooth surface which is nearly at right angles to the plane between the valves. The hinge line is straight and narrow. The beaks are situated just anterior of the center of the hinge line and do not project much above the hinge line.

Flat radial ribs are separated by grooves which are slightly wider than the ribs. The ribs are crossed by a few concentric growth lines. Near the ventral margin of the left valve there are 8 ribs in a space of 5 mm.

This new species may be distinguished from other species of the genus by the more rounded outline, fewer radial ribs and the lower elevation of the beaks. In the described species of *Allonychia* the beaks are much larger and considerably more elevated above the hinge line than in this new species. It is for this reason and the fact that a byssal notch could not be observed that this new species is only provisionally placed with *Allonychia.*

Dimensions:

	Left Valve	Right Valve
Length	10 mm.	7 mm.
Height	10+ mm.	7.5 mm.
Length of hinge line.....	4 mm.	3 mm.

In the advance notice of the fauna from the Caparro-Bellavista series it was announced that an *Ambonychia* was found. This was in reference to the form described here as an *Allonychia*.

The specific name *brevirostris* is used to indicate the short or low beaks of this new species as compared to the more elevated beaks of the other species of the genus.

Genus and Species Indet.

Plate—Fig. 7.

In the collection there are molds of a pelecypod which is roughly triangular in outline. The beak is central. On the side of the valve there is a wide, shallow depression. The valve was apparently smooth crossed only by a few concentric growth lines. Dimensions of the largest valve are: greatest length 13.5 mm.; height 8 mm.

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THE UNCOVERING OF NEW HAMPSHIRE BY THE LAST ICE SHEET.

JAMES WALTER GOLDTHWAIT.

ABSTRACT.

The detailed mapping of lateglacial ice marginal deposits and outwash on some fifty newly contoured quadrangles in New Hampshire for the State Highway Department, since 1925, has led to a complete revision of opinion regarding the way in which the last ice sheet disappeared.

Downwastage of the ice surface appears to have been fully as important as backward wasting of the periphery. In the hilly interior, it produced utterly ragged ice borders which shrank down in disorderly fashion until at last there were narrow tongues and remnants in the valleys, where kame terraces and crevasse fillings appear. Over the coastal lowland, seaward-flowing systems of meltwater drainage developed, which left strong parallel lines of kettled outwash and kames but no recessional moraine deposits and very few signs of sweeping by waves and shore currents. Thinning seems to have continued even while marine clay was being spread.

What was formerly thought to be a slanting marine waterplane that registered the exact amount and direction of lateglacial upwarping is now regarded as a waterplane of meltwater drainage, seeking escape from confining ice walls, and building deposits which show the touch of shore agencies only locally where areas of thin ice were least continuous. Field observations indicate similar features in Maine and Essex County, Massachusetts.

If downwastage played this large rôle in ice removal over wide areas, it is difficult to estimate the full amount of crustal upwarping, and to account for it by recovery from ice load; also, it is difficult to time successive stages in lateglacial rise of sealevel.

INTRODUCTION.

The manner in which the ice sheet uncovered New Hampshire, at the close of the last glaciation, is a question that has grown in interest during the last fifteen years. Antevs' extraordinary studies of varved clays in 1921-22 afforded what appeared to be exact rates of northward recession of the ice edge up the Merrimac, Connecticut and Hudson valleys. With these parallel records correlated, year for year, it was easy to draw lines across the intervening spaces transverse to glacial movement and parallel to such fragmentary "moraines" as were then recognized, so as to produce a map of the recession of the last ice sheet from New England and New York.[1] But enthusiasm for this new technique did not entirely shut our eyes to the fact that deglaciation is a three-dimensional process involving downward wastage of the surface as well as back wastage of the margin. A single paragraph written in 1925 puts it thus:—

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[1] Antevs, E.: The recession of the last ice sheet in New England, Amer. Geogr. Soc., Research Series No. 11, 1922; with map, Plate 6, compiled by J. W. Goldthwait.

> "The wasting of the ice sheet consisted in: (a) a melting back of its edge at rates usually between 200 and 600 feet a year; and (b) a thinning out of the sheet by slow downward melting of its surface at a rate as yet unknown, so as to expose the mountain tops and hillsides and leave irregular tongues of ice in the valleys. Water gathered in pools and larger lakes some of which were dammed by the ice sheet and consequently found new outlets as the edge of the ice receded, so that they spread forward or drained away or coalesced to form larger lakes, in a highly kaleidoscopic fashion. Valleys not flooded by lakes were occupied by outflowing rivers larger than those of today, and generally overburdened with sediment, which was spread out in various forms of 'outwash'. . . ."[2]

Since this paragraph was written, the complete contour mapping of New Hampshire by the U. S. Geological Survey and a detailed survey of gravel deposits for the State Highway Department by the writer and several assistants have afforded better opportunity to judge the relative importance of downward and backward melting of the ice. Meanwhile, emphasis upon stagnation and downwastage in Connecticut with possibility of very irregular removal of the final scraps, as first suggested by Flint,[3] has called for critical review of evidence from New Hampshire. Fortunately our field studies of sands and gravels over this State have come at a time of rapid development of pits and sections for highway construction, permitting old inferences from details of slope and form to be checked by actual exposure of structure at literally thousands of places.

The result of field observations here since 1925 may be summarized briefly as follows: In the hilly interior of the State, our mapping of ice-marginal kames and kame terraces, which outnumber all other types of gravel deposits, and of marginal stream channels cut across till slopes, indicates a long continued lowering of the surface of the ice while its thin and irregular edge shifted unevenly from contour to contour. Although deglaciation in general seems to have proceeded northward or northwestward, locally it was toward the east or west, according to the direction of upland slopes. In this rough terrain the ice seems nowhere to have had a well-defined "front" transverse to the ice motion of and more active stages of glaciation. How long and how general the ice lay stagnant in lateglacial stages it is not yet possible to say. Recessional moraines, if present at all, are mere scraps, not in line. Local groups of sharply defined ridges, formerly thought to mark halts in the retreat of the margin of an ice lobe,[4] seem now more likely to be crevasse fillings, formed at unknown distances within the wasting icefield and wholly without seasonal or climatic significance.[5] Some consist of till, while others are of gravel, sand, or even stratified silt. As for the valley deposits generally, ice-contacts appear on any or all sides of them. Plains, terraces, mounds and ridges thus bounded, lie scattered plentifully along valleys where meltwater escaped southward and southeastward. They are much more strongly aligned in the direction of ice motion than transverse to it. Both individually and collectively these records of lateglacial drainage imply downwastage of the ice surface almost to the valley floors instead of orderly "retreat" of a single wall or "front." The overlapping of thin marginal ice by glaciofluvial deposits of sand and gravel, followed by slumping, is abundantly suggested by gently undulating surfaces. Downvalley gradients of former stream profiles marked by outwash plains and ice-marginal terraces in branch valleys are so unlike in slope and direction as to be inconsistent with the idea that long open lakes were uncovered by ice retreating from end to end, and that their horizontal waterplanes were later upwarped; on the contrary, the record strongly favors the theory that stagnant remnants of ice impeded southward escape of meltwater over a zone of considerable width. More particularly in the low-lying coastal district of southeastern New Hampshire, detailed mapping of the lateglacial deposits has led to a complete revision of views regarding conditions of ice removal, marine submergence, and crustal upwarping.

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[2] Goldthwait, J. W.: The geology of New Hampshire, N. H. Acad. Sci. Handbook No. 1, p. 29; 1925.

[3] Flint, R. F.: The stagnation and dissipation of the last ice sheet, Geogr. Review, Vol. 19, pp. 256-289, 1929; also, The glacial geology of Connecticut, Conn. Geol. Surv. Bull. 47, 1930; and Deglaciation of the Connecticut Valley, This Journal, Vol. 24, pp. 152-156, 1932.

This shifting of emphasis from *recession* to *downwastage* recalls doubts felt by the writer some thirty-five years ago, when his study of sandplains in the Sudbury valley of eastern Massachusetts and a similar study by F. G. Clapp in the adjoining valley of the Charles River left unsettled the question whether the last ice sheet had receded so as to leave wide, open lakes or had wasted downward into fragments, as Clapp supposed, creating irregular groups of ice-bound pools with fluctuating levels.[6] The writer's uncertainty was increased later, when outwash deposits near Twin Mountain House on the northwest side of the White Mountains were found to have an intricate ice-contact pattern, implying highly irregular downwastage of the ice.[7] This example of downwastage, quoted by Flint[8] is now much more accurately contoured on the new Whitefield quadrangle (survey of 1934-35) and is seen to be closely associated with other icemarginal drainage features.

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[4] Goldthwait, J. W.: Op. cit., pp. 49-51.

[5] Flint, R. F.: Eskers and crevasse fillings, This Journal, Vol. 15, pp. 410-416, 1928.

Among the long-accepted items of lateglacial history of New Hampshire which our revised views lead us to discard are: (a) three lines of halt or readvance of the ice edge, known as the Newington moraine, the Claremont-Winnepesaukee line, and the Bethlehem moraine; (b) wide, open lakes in the Winnepesaukee, Merrimac-Pemigewasset, Contocook and Ashuelot valleys; (c) the reconstructed waterplane and shoreline of the lateglacial or "Champlain" sea, as shown by "beaches" and "wave-cut cliffs" in the coastal area, and the computed crustal upwarping of that waterplane.

RECORDS OF THE INTERIOR.

"Recessional Moraines."

While Antevs was computing definite rates of annual recession of the ice margin in the Connecticut and Merrimac valleys by means of varved clays, in 1921, the writer discussed with him all known signs of temporary halting and readvance of an ice front in New Hampshire and made a rapid search in the field for more. There was hope of discovering important oscillations of climate during deglaciation in New England which might be correlated with those registered by the moraines in western New York State and the Great Lakes region, studied by Taylor and others.[9]

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[6] Clapp, F. G.: Relations of gravel deposits in the northern part of Glacial Lake Charles, Massachusetts, Jour. Geol., Vol. 12, pp. 198-214, 1904; and Goldthwait, J. W.: The sandplains of Glacial Lake Sudbury, Bull. Mus. Comp. Zool., Vol. 42, pp. 263-301, 1905.

[7] Goldthwait, J. W.: Glaciation in the White Mountains of New Hampshire, Bull. Geol. Soc. Am., Vol. 27, pp. 263-294, 1916.

[8] Flint, R. F.: Op. cit., p. 279, 1929.

[9] Taylor, F. B.: The glacial and postglacial lakes of the Great Lakes region, Ann. Rept. Smithsonian Inst. for 1912, pp. 291-327, 1913.

The Line of the Bethlehem "Moraine."

A zone of massive kettled outwash had already been studied in Bethlehem and Littleton, in northern New Hampshire[10] and intepreted as a recessional moraine, although its climatic significance had not been particularly stressed. Varved clay sections at Fifteen Mile Falls, ten miles west of Littleton, indicated to Antevs a halt of the ice margin and readvance after some 280 years, at a point nearly in line with the Bethlehem "moraine."[11] Deep excavations during the construction of the Comerford Dam at East Barnet, several years later, clearly exposed two sheets of till and the interbedded varved sediments, by which Lougee was able to confirm Antevs' measure of the time interval for the halt and readvance.[12]

Meanwhile Crosby, who had made elaborate studies of the drift in and near the Fifteen Mile Falls project for the New England Power Company, urged correlation of these records with ice-marginal kames midway between them and the Littleton end of the Bethlehem moraine and with a body of stratified silts overriden by till many miles farther east, in the Peabody River valley south of Gorham.[13] Thus, it seemed, the supposed halt represented by the Bethlehem moraine might be traced along a wide front. Now that our gravel survey on the new contour maps has been completed and has found ice-marginal kames, ridges and terraces abundantly both north and south of Crosby's line, and has shown that these features persistently occupy the main valleys regardless of valley orientation, and hence were localized by the preglacial topography, it seems no longer reasonable to interpret any of these stratified drift deposits as moraines. The thick, kettled outwash with boulder-strewn surface between Littleton and Bethlehem, which first gave rise to the idea of an icefront standing in deep water along this eastward segment of the Ammonoosuc Valley, can now be mapped more correctly on the newly contoured quadrangle and appears not only much less continuous than was once thought but also much less definitely ridgelike in detail than descriptions by Agassiz, Upham and the writer implied. The general east-west course of this zone of outwash can be attributed to the east-west trend of this particular segment of the valley. As for Crosby's correlation of the over-ridden silts near Gorham with those at Fifteen Mile Falls, one must object that, if they are varved, these have not been measured and matched, and that the two localities are 25 miles apart; moreover, in the rough country that separates them, kame terraces and kames follow opposite sides of the deep valleys along a winding course at a nearly uniform elevation for long distances, especially in the township of Jefferson, thus indicating the downwastage of a thin and ragged ice margin instead of the northward retreat of a high ice "front."[14]

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[10] Goldthwait, J. W.: Op. cit., pp. 263-294, 1916.

[11] Antevs: Op. cit., pp. 83-84.

[12] Lougee, R. J.: Time measurements of an ice readvance at Littleton, N. H. Proc. Nat'l Acad. Sci., Vol. 21, pp. 36-41, 1935.

[13] Crosby, I. B.: Extension of the Bethlehem, New Hampshire, moraine, Jour. Geol., Vol. 42, pp. 411-421, 1934.

The Claremont-Winnepesaukee "Line of Halt."

Antevs found reason to suspect a line of halt and readvance farther south, near Claremont, New Hampshire, in a district where varved clay sections did not match and where one section of lake silt especially was covered discordantly by four feet of coarse cobbly gravel, like outwash from a readvancing ice front.[15] Starting from this point in the Connecticut Valley, scattered ice-contact deposits were picked up by the writer in reconnaissance eastward and northeastward at Lempster, Lake Sunapee, Winnisquam and Laconia, toward Lake Winnepesaukee, where Upham, fifty years earlier, had reported laminated clays overlain by till at Weirs, Alton, and Wolfeboro. The only section exposed there in 1921—the one at Weirs—was measured by Antevs; but the clay beds were found to be much distorted and disturbed by sliding or ice pressure and could not be matched with the varve sections in the Merrimac Valley. There seemed to be about 200 varves in the Weirs section. Hummocky deposits of sand near Center Tuftonboro, just east of the lake, were accepted as another mark of a lingering ice border. On various grounds, Antevs assumed a time interval of from 200 to 400 years for oscillations on this Claremont-Winnepesaukee line; but he could not find a record of the halt either in moraine deposits or in varved clay in the Merrimac Valley, nor any in the Hudson and Mohawk Valleys.

A somewhat detailed description of these features was given a few years later in the writer's "Geology of New Hampshire."[16] It was already realized then that the moraines "do not form a continuous line by any means, but seem to have been built only at points where conditions were most favorable. The recognition of this line of halt is recent and its full significance is as yet uncertain." Particular attention was called to a series of ten or twelve distinct ridges of bouldery till, supposedly stadial moraines, at the south end of Lake Sunapee[17] and to a less orderly cluster of ridges and hummocks partly of till and partly of silt at Laconia.[18] "While these moraine scraps are separated by gaps of fifteen or twenty miles, where the ice edge either left no good mark on the hills or where the marks lie undiscovered, evidence seems to justify the view that there was a halt of some duration here, during the recession. There are few places north or south of the zone mentioned where deposits like them have been noted, although searched for."[19]

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[14] The mapping of these features on the new Mt. Washington and Whitefield quadrangles by R. P. Goldthwait will be discussed by him in a forthcoming paper.

[15] Antevs, E.: Op. cit., pp. 81-82.

[16] Op. cit., pp. 49-52.

The uncertainty thus expressed in 1925 has steadily grown, with the progress of field work on new contour maps, until it can now be said positively that the correlation of these features across the State from Claremont to Winnepesaukee is not justified. Although the ridges near Lake Sunapee resemble the so-called stadial moraines of the Finger Lakes region,[20] the Berkshires [21] and central Massachusetts,[22] they are better explained as crevasse fillings than as ice-border embankments. Their diagonal courses down the steep side slopes of the basin might of course be due either to the slanting contact of an ice lobe with the mountain side or to crevasses opened by strain of ice movement within a lobe. The distance between successive ridges is not very different from that of annual recession as computed by Antevs from varved clays in the Connecticut Valley. But the ridges have side slopes that are equally steep, as if both were determined by contact with the ice. They are broken and less diagrammatic than first supposed. The Laconia ridges seem even more surely to be crevasse fillings, for they consist largely of fine, laminated lake sediments, and they trend in various directions. Still more significant is the discovery that sets of ridges like these are not limited to the Claremont-Winnepesaukee zone, as first supposed, but occur at a number of places off that line,—for example, near the Orange Summit, and in Lebanon, South Danbury, Orford, Newfound Lake and East Andover, quite without alignment and apparently dependent upon local topographic conditions. Finally, the four feet of cobbly gravel overlying the lake beds at North Charlestown, which Antevs was inclined to interpret as outwash from a readvancing ice edge, now appears instead to be a sheet of river channel gravel spread across truncated lake beds during the period of emergence and terracing of the valley floor. Although the concept of an important ice-margin oscillation along a Claremont-Winnepesaukee line has won a place in the literature[23] there seems to be little ground for retaining it.

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[17] Op. cit., Figure 15.

[18] Op. cit., Figure 12.

[19] Op. cit., pp. 50-51.

[20] Tarr, R. S.: Watkins Glen-Catatatonk Folio, U. S. Geol. Surv., No. 169, 1909.

[21] Taylor, F. B.: The correlation and reconstruction of recessional ice borders in Berkshire County, Mass., Journ. Geol., Vol. 11, pp. 323-364, 1903.

[22] Alden, W. C.: The physical features of Central Massachusetts, U. S. Geol. Surv. Bull. 760B, 1924.

Valley Outwash.

Field studies before 1925 were chiefly in "lateglacial lake" areas of the Winnepesaukee, Merrimac and Connecticut valleys, and in the lowland of southeastern New Hampshire, where valleys were ill defined and contour maps obsolete. Lateglacial conditions in tributary valleys of the interior were suggested, however, by the case of the Cocheco River in the towns of Farmington and Rochester, where "swift flowing rivers running through ice canyons and tunnels built a fine chain of eskers and kames in midvalley and an almost continuous line of kame terraces against the hillsides."[24] These deposits were thought to have accumulated in pools of water on opposite sides of a short ice tongue, forming one by one as the ice drew back. The down-valley gradient of terraces in the Cocheco valley was about 20 feet to the mile,—much steeper than the slant due to crustal warping, which was estimated to be six feet per mile in the same direction.

Since this was written, the State Highway Department's gravel survey has carried the detailed study of glacio-fluvial deposits into every significant valley in the state, as fast as new contour maps were available. Features like those of the Cocheco were found in most valleys that drain toward the south or southeast. The lateglacial stream gradients range from ten to 25 feet per mile, with little regard to compass direction, showing that the water in them was flowing toward the trunk lines of drainage, with stream profiles governed by ice on the one hand and till or rock slopes on the other.

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[23] Goldthwait: Loc. cit.
Antevs: Loc. cit., also The last glaciation, Amer. Geogr. Soc. Research Series No. 17, pp. 152-153, 1928.

[24] Goldthwait: Op. cit., p. 35, 1925.

Gravel terraces are largely if not wholly constructional, with conspicuous ice contacts facing valley axes. Usually there seems to be but one ice-contact terrace in a valley, in contrast with conditions reported from the lower Connecticut.[25] There is little if any sign of lateral cutting by ice-marginal streams into till slopes or of scouring of ground between ice-marginal pools. This implies that drainage at that stage was almost wholly through or across thin crevassed ice. Gently undulating borders of plains commonly suggest a slow collapse of deposits laid on thin ice. In particular, the descent of a lateglacial stream profile down a valley appears to be uniform for long distances, without abrupt drops over temporary thresholds.

While the familiar hypothesis of construction of kame terraces by up-valley growth of deposits at the end of a receding tongue of ice may still be invoked to explain these facts, we are nevertheless troubled by the question,—what was the form of the central ice tongue? Was it short, steep and wide, or long, low and slender? Was the ice in the valley wasting away more by backward recession or by thinning over a zone five, twenty-five, or fifty miles wide? So far as the kame terraces have substantial continuity and rather steady downvalley gradients, they suggest thin, slender tongues of ice bordered by long pools that were fully connected by passages through the ice. This is conspicuously the case, for example, in the Soucook valley in the town of Loudon, in the Lamprey River valley in Deerfield and Raymond, and in the valley of Beaver Brook in Windham and Pelham. The zone of thinned ice during late stages of wastage would seem to have been much wider than formerly assumed by the writer and others, and more nearly comparable to the conditions described by Flint in Connecticut.

At the same time, it seems certain that in these New Hampshire valleys, as in Connecticut,[26] the removal of ice proceeded in a northerly or northwesterly direction. Evidence lies in the sharp contrast between deposits in valleys that discharge in opposite directions. Those which drain northward usually contain ice-contact deposits that register ponding of deep meltwater behind thresholds of rock and till with overflow in a southerly direction. The waterlevel to the north is marked by nearly accordant tops of kame terraces, deltas and general upper limit of outwash, adjusted to the controlling threshold;

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[25] Flint, R. F.: Op. cit., 1929, 1930.

[26] Flint, R. F.: Op. cit., p. 155, 1932.

the southward discharge, where structure was not too resistant, is indicated by a spillway channel with sometimes a boulder pavement or potholes in the stream bed, and by rapid descent to the much gentler long profiles of the more freely flowing southward drainage lines. Even in these cases, however, the drainage basins on the north and northwest sides of divides appear to have been occupied by thinned and ragged ice during the accumulation of sediment, and not for any length of time by open water, if one may judge from the prevalence of kames and marginal kame terrace deposits around their borders and an almost complete absence of lake-bottom sediment from their floors.

Marginal Drainage Channels.

Inasmuch as detailed field work before 1925 had been limited largely to the lowland areas of southeastern New Hampshire and to the poorly contoured areas around Lake Winnepesaukee, Lake Sunapee and the White Mountains, channels cut by overflow from highlevel drainage basins had not been found in large numbers and were not given much place in the account of that date. The Handbook did, however, describe gaps cut across till barriers by westward discharge of "Glacial Lake Winnepesaukee" at Winnisquam and Lakeport, and a pair of newly-discovered "spillways" that led from "Glacial Lake Belknap" toward Laconia. It was intimated that future studies in districts similarly situated would probably reveal many cases like them.[27] That expectation has been abundantly fulfilled with new contour maps to expedite discovery. But in many instances drainage channels have turned up in situations not easily accounted for by the hypothesis of a retreating ice front and bordering lakes. There are many marginal river channels; but few if any lake spillways.

While mapping the gravel deposits on the old Whitefield quadrangle south of Lancaster for the State Highway Department in 1930, Richard Lougee found a group of district channels traversing the long till slope and terminating in a long kame terrace near the Connecticut River. The generalized contours gave no suggestion of these details, which Lougee interpreted as marks of a westward escape of ice-marginal waters from a lake in the Israel River basin. This discovery led to another, at Jefferson Highlands on the Mt. Washington quadrangle, where several channels cut the slope that separates

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[27] Goldthwait, J. W.: Op. cit., pp. 39-42, and Figure 12, 1925.

Stag Hollow from the Israel River lowland. New surveys of these two quadrangles in 1934-35 have made it possible to trace out and map the details of channel cutting and terrace building here with greater accuracy than before, and to find in them an indication of downwastage of ragged ice margins against the mountains.[28]

On quadrangles farther south our gravel survey has revealed many examples of marginal channels descending into kame terraces. Thus, Lougee found lines of former drainage on the west and north sides of Hubbard Hill in North Charlestown (Claremont Quadrangle), and George W. White located an important channel and kame deposit near the Contocook River in Henniker (Hillsboro Quadrangle). Small but unmistakable channels had been noted on the Wolfeboro quadrangle by the writer as early as 1920; but these could not be satisfactorily explained until the weight of evidence brought recognition of extreme irregularity of icemargins fitted to upland slopes in all directions. Some thirty such channels have been located by the writer and his associates on the Mt. Cube, Mascoma, Cardigan, Winnepesaukee and Wolfeboro quadrangles. In nearly all cases the channeling indicates escape to the south or east or west; but in one or two instances it was toward the north. The cutting in nearly every case is through till or against kame gravels; rock has been channeled only in Jefferson and in Lyme. It seems, then, that these streams were short lived. Boulder pavements are not so common nor so good on channel floors as one might expect from the plentiful supply in the drift. Steepened banks and gently graded floors are often rather typical, blending upstream into slopes that either rimmed an old lake or more likely a basin occupied by downwasting ice when the stream found this course. Nowhere have we found direct evidence of wide open lakes; on the contrary the deposits in these basins are scattered kames and kame terraces, more often marginal than central in their positions. Some channels are so related to slopes as to deny origin from lakes and require a river flowing off the ice. Others which might be regarded as spillways from proglacial lakes show strange inconsistencies of altitude. Thus near East Plainfield (Mascoma quadrangle) at the southern end of Great Brook drainage basin, where overflow from an ice dammed lake would be expected to have followed a gap on the Claremont road at about 1,230 feet, there is no sign of river scour, although a higher gap only a half-mile to the east has a channel sharply cut through till. The initial surface of the till here was fully 40 feet higher than that in the other gap and the finished channel floor is 15 feet above it, or 1,245 feet by precise leveling. If there was a lake ready to spill through these gaps, then the lower of the two was blocked by ice all the time the upper one was being channeled. It seems more likely that the higher gap was channeled by a superglacial stream which became superimposed on that col, and that no lake developed to select a lower outlet. In other places, channels occur far up hillsides on open slopes rather than in cols, where it is impossible to relate them to proglacial lakes.

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[28] Goldthwait, Richard P.: unpublished studies, 1937.

Ultimate Northward Recession in the Connecticut and Merrimac Valleys.

Whatever the indications of general downwastage of the ice on to the upland surface and thinning down into the lowest valleys, a final northward deglaciation in Merrimac and Connecticut Valleys seems to have been established by Antevs' measurements and matchings of varved sediments. Independent measurements of newly exposed sections of varves around Hanover, at points in the White River Valley and at Fifteen Mile Falls, by students at Dartmouth, notably by R. J. Lougee, corroborate Antevs' original matching. In spite of the fact that he actually reached "bottom" at only a few localities,[29] there can be little doubt that the varves overlap northward, as Antevs first claimed in 1921, showing that the deglaciation proceeded generally in that direction. The approximate correspondence in rates of retreat in the parallel valleys, Connecticut and Merrimac, as worked out from varved sediments, at least as far north as the line Cohoes, New York—Putney, Vermont—Boscawen, New Hampshire, lends some plausibility to the reconstruction of successive positions of a straight ice "front" across the wide intervening spaces, as originally drawn by Antevs[30] but the correctness of such representation of many successive ice fronts is seriously open to question, in view of the extremely ragged ice margins required by the features already described. Indeed, ice-contact slopes are not lacking in the thick sandy deposits of the Merrimac Valley.

After all, there is no contradiction between the varved deposits and the icemarginal features. It is conceivable that ablation may have thinned the ice down to almost nothing, with gentle southward slope over wide areas of upland while ice still remained fairly thick and partly stagnant in the broader and deeper valleys; and that finally the extremities of the valley remnants wasted northward at the rates which Antevs has worked out.

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[29] DeGeer, G.: Geochronology as based on solar radiation, Science, Vol. 66, p. 459, 1927.

[30] Antevs, E.: Op. cit., Plate 6 and pp. 67 and 74, 1922.

RECORDS OF THE COASTAL REGION.

"Recessional Moraines."

Just before the writer's study of southeastern New Hampshire began, in 1917, Katz and Keith had traced a deposit of stratified drift from Biddeford, Maine, southwestward across New Hampshire to Newburyport, Massachusetts, and had called it the "Newington moraine."[31] They took this to mark an important halt in retreat of the ice border from the seacoast. Without accepting this broken, zigzag line of kames as a single continuous moraine, the writer attached some significance to that portion known as Merriland Ridge in the township of Wells, Maine, and sought for its southwestern extension across the towns of Dover, Madbury and Lee, New Hampshire. A map (Fig. 8) in the handbook and brief statements show that this search met with indifferent success.

> "As it receded across the submerged zone, the ice edge halted from time to time, building some large morainic embankments, such as Pudding Hill in Madbury and the Glenwood Ave. ridge north of Dover. These have typical knob and kettle topography like the terminal moraine on Long Island; and like it, also, each moraine has a smooth frontal apron along its seaward margin where sands were spread forward from the ice border. These aprons match closely in altitude the raised beaches near them. Other mounds and ridges of morainic nature in Barrington and Lee probably mark the two lines of halting noted above (coarse dotted pattern) and form a natural continuation of the moraine which has been traced from Biddeford, Maine, to Berwick and Dover by Keith and Katz, called by them the 'Newington moraine.'[32]
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> "The recession of the ice border across this submerged zone was unsteady and interrupted by halts. Where the edge stood still, morainic banks or ridges were heaped up, with aprons of sand washed forward, like the great terminal moraine and outwash

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[31] Katz, F. J., and Keith, A.: The Newington moraine, Maine, New Hampshire and Massachusetts, U. S. Geol. Surv. Prof. Paper, 108-B, 1917.

[32] Op. cit., p. 30.

apron on Long Island but on a much smaller scale. These are so small and scattered as to suggest that the ice border never stood long at any one line, in this part of the State. The two best examples . . . . Pudding Hill and the Dover moraine ridge mark two positions of the ice edge, about five miles apart; and are very nearly in line with a moraine that has been traced through southern Maine from Saco and Biddeford westward to North Berwick. This was named the Newington moraine . . . . . by Keith and Katz because of its supposed extension down past Dover Point to the town of Newington. Since the two moraine banks and aprons, described above, at Dover and Madbury resemble the Maine moraine closely in form and structure and lie in direct line with it, while the Dover Point and Newington deposits are dissimilar and out of line as well as out of harmony with the direction of ice-flow of the continental glacier, there is good ground for regarding them as fragments of the Saco-North Berwick moraine line. Repeated search for an extension of these ice border deposits southwestward through the townships of Barrington, Lee, Nottingham and Epping, where excellent topographic maps can be used, has failed to bring to light any good records there, although in Fremont and the southern part of Raymond are several strongly marked lines of moraine, both gravelly and rocky, which Hitchcock long ago noticed. These too are only scraps, somewhat scattered, and not in every case distinguishable from glacial deposits of other origin. It seems fairly certain that they mark the same zone of retardation in ice recession as the Saco-Berwick moraine. No one has yet traced this line west of Fremont; but it presumably extends across the lines of glacial flow, in a southwesterly direction past Nashua to join a well defined zone of halt and readvance at Amherst and Northampton, Massachusetts. According to Antevs, the halt there occupied two or three hundred years."[33]

This forecast of what might in time be found along the extension of the Saco-Dover-Fremont line grew out of a fancied resemblance of the New England features to the famous Salpausselkä moraines in Finland. The Merriland Ridge and the Pudding Hill deposits were suggestive, indeed, but disappointingly discontinuous. Field work during the next decade revealed no additional records that could be used to extend these moraines over into Massachusetts. With detailed mapping of gravels completed, it is now clear enough that no such halt of an ice front is registered. The "moraine ridges" in the town of Raymond and the kettled kamefield in the town of Fremont, separated from each other and from the Madbury embankment by several miles, are no more related to them than they are to kames and outwash plains to the north and south.

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[33] Op. cit., pp. 33-34.

The "moraine embankments" of Dover and Madbury differ only in size and linear trend from ice-marginal plains and kames of great diversity and number. From the first, the outwash deposits of the coastal area have been hard to relate to an orderly receding ice edge bathed by the Champlain Sea. The general southeastward slant of their surfaces, accompanied as it often is by diminishing coarseness of sediment and by dipping foreset beds gives reason indeed to regard them as built by powerful and persistent flow of meltwater; but the proximal edges of the plains are often ill defined, unlike ice contacts, and the distal margins with rarely a trace of distributary lobes are as irregular as the rest. Kettles in some cases are deep and steep sided, in others shallow and indefinite; but these and the irregular ice contacts suggest accumulations within and upon a thinned and discontinuous mass of land ice which lacked any sharply defined edge.

Very large outwash plains such as those at Rochester, poorly shown on the contour sheets of fifty years ago, lack the simplicity formerly attributed to them. They seem to be complex in form and in date of origin. What is more, their internal structure, better seen now in enlarged gravel pits than it was twelve years ago, leaves considerable doubt about the exact elevation of the water surface at which or beneath which they were spread. Comparison of these old contour maps with the excellent new Haverhill and Newburyport quadrangles shows that plains like these are smaller, more numerous and more irregular in outline than they formerly appeared to be. Like the other marginal deposits, they do not fall into lines transverse to ice movement, but lie conspicuously parallel to it.

Indeed, on purely theoretical grounds, continuous recessional moraines are scarcely to be expected in a region as hilly as this. Exposures of overridden varved clays at Amherst, Massachusetts, Fifteen Mile Falls, New Hampshire, and other places show that locally, at least, the ice had active motion even at its edge. But the rates of motion may have been very different within short distances on the ice margin, when the ice sheet had thinned down close to the uneven rock surface, and increasingly variable and diverse as downwastage continued. Concentration of drift into a terminal moraine required an approximate balance between forward movement and backward wastage of ice. Both processes may well have been variable at different points along a given sector, movement being influenced by irregular topography as just suggested, and melting being fast or slow because of irregularly distributed load of drift gathered from the hilly terrain itself. Balance then between the two variables would be unlikely for any distance along the ice edge and moraine deposits would be discontinuous. In smoother country like the Great Lakes region, where movement would be steadier and drift content and ablation more uniform, approximate balance between the two processes would result in relatively continuous moraine ridges. Granted that stagnation of ice over New Hampshire in late-glacial stages is highly probable as the result of thinning by surface ablation, it is not necessarily implied by the absence of recessional moraines.

Other Ice-Marginal Deposits.

The "moraine embankments" discussed in the foregoing section cannot be satisfactorily differentiated from outwash deposits of other types. Although their distinctive features were supposed to be (a) linear trend at right angles to ice movement, (b) kettled ice margin on the north and seaward slope to the south, and (c) coarser and more crumpled beds in the proximal zone grading to finer and more uniform beds in the distal portions, the best of these "moraines" fails to meet specifications. For example, (a) the Pudding Hill and Dover ridges run nearly east and west, or diagonal to glacier movement. Katz and Keith, seeking a nearly continuous line for their "Newington moraine" but missing the two ridges just mentioned, mapped it as turning abruptly at right angles at Dover and as running several miles south-southeastward to Dover Point, beyond which it turned again into a northeast-southwest course through Portsmouth to Newburyport. There again it seemed to follow a line of kettled drift southeastward. Their supposed moraine was thus markedly zigzag instead of consistently transverse to ice motion. Forty years earlier, Upham had interpreted the Dover-Newington section as a great kame, built by a glacial river that ran between ice walls on a course parallel to ice motion and to the seaward slope of the ice surface. This would seem today to be the better explanation. (b) While kettled surfaces mark the crests or backbones of the best "embankments," they are plentiful as well in outwash plains that lack linear form or transverse trend—plains which seem as often to have steep slopes on the south, east, or west sides as on the north. Examples include the plain at Barbadoes Pond in the town of Madbury and Spruce Hole in Durham. In some cases, kettles are as conspicuous in the central or southern portions as in the northern. (c) Although southward slope of surface and gradation from gravel into sand indicate flow toward the south in many instances, there are plenty of striking exceptions. Steep westerly or northwesterly dips of foreset beds covered by thin horizontal topsets are exposed over wide areas and to great depth in the plains of Newmarket, Greenland and North Hampton. Beds jammed and wrinkled as if by ice shove can be seen at the southwest corner of a wash plain near Back River School in Madbury. The great diversity of form and structure and in direction of growth of these delta-like aprons of outwash is easy to account for if the wastage of the ice consisted chiefly in downmelting of an uneven surface with broad passageways and pools to catch sediment delivered to them from one side or the other; it is hard to explain as a record of successive retreats and halts of a single ice wall or "front."

The fact is, alignment of these deposits is definitely along northwest-southeast lines, ***parallel with*** ice motion. The small-scale map of our gravel survey of the southeastern part of the State makes this clear. (Fig. 1.) Beginning with the line which comes down along the Maine-New Hampshire boundary in Milton and becomes part of the "Newington moraine" near Dover Point, one can count nine or ten definite lines of concentrated outwash, approximately parallel and about five miles apart. It seems easier to explain this persistence of lines of kame and outwash plain construction by seaward-flowing systems of glacial drainage consequent upon a thinning ice sheet than to try to relate them to backward recession of an ice front. It must be pointed out, also, that the southeastward courses of the lateglacial drainage lines, here, are wholly independent of control by the present slopes and drainage of the area. The region is an undulating lowland, and the stream systems arborescent, with very crooked main stems, quite disorderly in pattern.

Farther inland, where the upland rises and takes on stronger relief, with valleys, which may or may not follow a southeasterly course, the lines of outwash shift their direction to conform to the topographic control. Thus, as seen on Fig. 1, we find the pronounced line of kames, terraces, and outwash plains of the Soucook Valley running due south for some 20

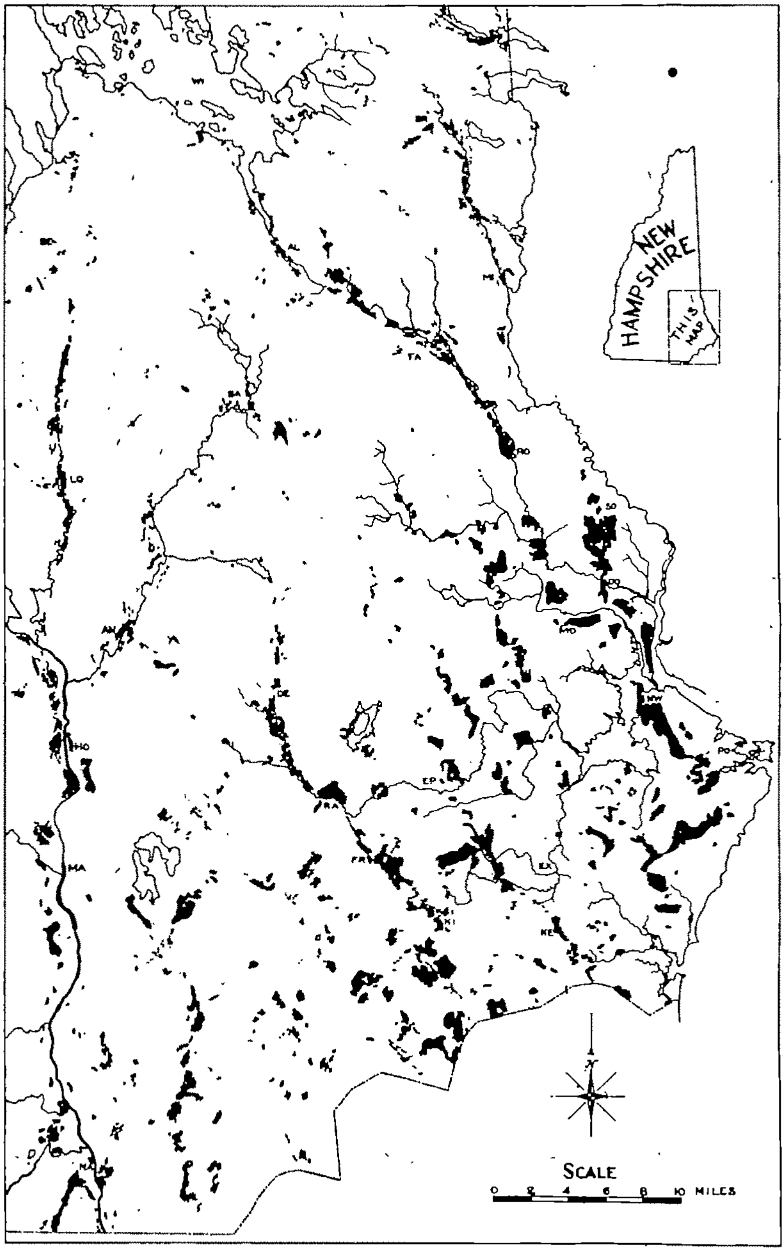
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Fig. 1.

miles from Belmont to Pembroke and continuing down the Merrimac eight miles more to Hooksett. One of the southeastward lines of outwash of the coastal area which enters Fremont from Raymond is seen to have its source farther up the valley of Lamprey River in Deerfield, where the trend of the deposits is from north to south in obedience to topography. The southeasterly course of kames from Alton Bay to Farmington and North Rochester is undoubtedly due more to guidance by the long valley of Cocheco River than to the surface slope or movement of the ice sheet. Over central and northern New Hampshire, as explained on earlier pages, outwash deposits follow the valleys more and more closely with greater relief as the controlling factor.

Emerged Marine Strandlines (?)

Records of lateglacial submergence of the New Hampshire coast were described in 1925 as follows:

> "As the ice edge melted back from the coast of New Hampshire the sea spread inland fifteen or twenty miles beyond the present shoreline, flooding Portsmouth, Dover, Newmarket, Exeter and a score of adjoining towns . . . . Islands singly and in clusters lay in the sea. . . Many of them were drumlins, standing knee-deep in water; and on their exposed ends and sides the waves . . . cut cliffs and built bars and beaches. The submergence appears to have been rather short-lived here and elsewhere along the coast of New England and the Maritime Provinces. The watermark at the 'upper marine limit' is distinct only in those places where there was full exposure to the sea, ground easy for waves to cut into, material easy for shore currents to move, and a slope favorable to wave action and undertow. Where sea cliffs were cut in the

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Fig. 1. Map of southeastern New Hampshire, showing 750 gravel deposits as mapped by the State Highway Department on U. S. Geological Survey quadrangles. Deposits containing only sand are not included. Localities shown by initial letters as follows:

(In northern part) WI, Lake Winnepesaukee; LA, Laconia; BE, Belmont; AL, Alton; BR, Brookfield; MI, Milton.
(On Cocheco River) FA, Farmington; RO, Rochester; DO, Dover.
(Eastern corner) SO, Somersworth; MD, Madbury; NW, Newington; PO, Portsmouth.
(Southeastern part) EX, Exeter; KE, Kensington; FR, Fremont; KI, Kingston.
(On Lamprey River) DE, Deerfield; RA, Raymond; EP, Epping.
(Western part—on Soucook River) LO, Loudon.
(On Suncook River) BA, Barnstead; AN, Allenstown.
(On Merrimac River) HO, Hooksett; MA, Manchester; NA, Nashua.

seaward ends of drumlins . . . the cliffs are no longer steep banks, but have been softened by frost creep, slump or rainwash. Platforms developed in front of these cliffed headlands or islands are in some places simply wave-swept slopes of till, paved with cobbles and boulders; in other places they have a thin mantle of gravel or sand such as would be expected more generally along a well developed shoreline. Some islands, like Long Hill and Barker's Hill in Stratham were tied together or connected with the mainland by bars where beach drifting was active, or had hooked spits built out on their sheltered ends, like Stratham Hill. Gravel pits in these show typical rolled and stratified beach gravels and sands. . . Measurements of the present altitudes of the marine limit indicate that the points which according to theory once registered a common level or waterplane no longer agree in level but fit rather closely a plane that slants southeastward at a rate of between five and six feet to the mile. . . That this emergence was already in progress when the coast was uncovered is suggested by the delicacy with which wave work is registered at the marine limit; that it was both steady and rapid is suggested by the lack of any strongly defined shoreline between the marine limit and the present shore."[34]

This interpretation of former strandlines needs revision: for our mapping of the gravel deposits on the newly contoured sheets and the study of sections exposed in scores of new gravel pits since 1925 convinces us that many of the "shoreline features" are largely—and perhaps wholly—of glaciofluvial origin. What were once regarded as seacliffs on drumlins may in some cases be terraces cut by ice marginal streams; in other cases they are abnormally steep initial slopes of drumlins abutting on icemarginal outwash deposits. Two of these deserve special mention: a flat topped triangular terrace at the west end of Newfound Hill in Kensington and a narrower one at the east end of Moulton Ridge in the same town. Although both the form and the vertical position of these justified consideration of them as watermarks of the upper limit of marine submergence before sections were opened, and one of them, accordingly, had been carefully measured and used as one of the points for reconstructing the marine waterplane, deep gravel pits that have been opened in them since that time show convincingly by their structure that they are ice-contact deposits built in small pools against the drumlin ends. Since their elevations approximately match those of other outwash deposits of diverse shapes and sizes in their vicinity, falling into line with them on the map, as already described, we may infer that such pools in the ice formed a well connected system draining seaward in thinned and wasting ice and not much above the sealevel of the time.

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[34] Goldthwait: Op. cit., pp. 29-32.

Most of the "beach ridges" lack perfect horizontality: they rise and fall gently, instead, after the manner of kame deposits. Their internal structure now abundantly exposed often shows poor sorting, slumped crossbedding, boulder beds, and isolated boulders. Rarely do they display that thorough layering, with separation of shingle from sand, which distinguishes shore drift from outwash. Still more disconcerting is the fact that a number of these beach-like features occur in most unlikely situations, without proper associations or characteristic curvature, while those drumlins which according to the theory stood most openly exposed to the sea furnish the least convincing watermarks of all. Of course, one may argue that even wave-swept sediment might have been rendered irregular by shore ice which crowded rocks ashore and became so involved in deposits as to cause sagging or pitting of the surface after crustal warping had brought it above the reach of the sea; but the extent to which such a modifying factor is called for leaves little place for normal shore processes. Where so many things point to downwastage of the ice and well organized drainage systems sweeping gravels and sands into pools and pockets, it appears wise to reject all but the clearest cases of shore forms. A hooked spit at the west end of the Stratham Hill drumlin[85] is one of these.

Sea-Floor Clay.

Belief in lateglacial submergence of the coastal area depends not only upon the widespread deposits of sand and gravel but also on associated deposits of clay, used for brickmaking at Rochester, Gonic, Epping and Exeter. These were long ago described by Upham and Hitchcock, and assigned to marine origin because of the presence in them of fossil shellfish, particularly *Leda.*[86] Although no authentic discovery of such shells has been reported since Upham's time, from New Hampshire clays, there seems to be no reason to doubt the older record. The clays closely resemble known marine clays of the

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[85] Op. cit., p. 31 and Figure 7.

[86] Hitchcock, C. H.: The geology of New Hampshire, Part 3, with Chapter 1, Modified drift by Warren Upham, pp. 165-167, 1878.

St. Lawrence Valley and other regions in their utter lack of textural lamination, in contrast with the varved clays of fresh-water areas. Their continuity northeastward through Maine past Portland and Brunswick, where they spread far inland, become more continuous, reach greater altitudes and are associated with shell-bearing sands and gravels leaves little doubt of their marine origin.

Since fine sediments collect only in quiet water, it is not likely that the clays reach up to the limit of submergence anywhere. At the Epping brickyards, however, broad clay flats lie at 140-150 feet elevation, or within ten or twenty feet of such watermarks as have hitherto been taken to mark late-glacial sealevel. Near Exeter they are much lower, while at Gonic they reach 200 feet.

If the removal of ice from the coast consisted, as we have come to think, of downwasting over a wide area, so that the waves and shore currents had little chance to mark out shorelines, then the detail of topography of these clays acquires fresh interest, inasmuch as lingering masses of ice might be expected to have imposed their outline on the seafloor sediments as well as upon the coarser sediments of shallow water. No thoroughgoing study of the morphologic detail of the clays has been made. That some tracts are level and others definitely undulating and of variable thickness is obvious enough; but it is not certain how far the unevenness is due to thin clay deposits on an uneven base and how far, possibly, to lingering ice preventing uniform deposition.

A more promising field than New Hampshire for testing this hypothesis is in Cumberland County, Maine, where clays are much thicker and more widespread, but associated, as in New Hampshire, with high pitted plains and kames of gravel and sand. Wide areas of sag-and-swell topography in marine clay are traversed by highways in the townships of Buxton, North Yarmouth, and Waterboro, for example. Although elaborate stream dissection if carried far beyond the mature stage of the cycle can produce hummocks and hillocks very much like ice-contact features, that, in the writer's opinion, is not the case in the areas just mentioned. Nor can the sags and swells be attributed to artificial grading of clay areas that were formerly worked as brickyards: these examples lie far beyond the reach of sites thus used. One hesitates to resort to the theory that the sag-and-swell surface was produced by glacial readvance over a seafloor; for there seems to be no deposit of till, boulders, or coarser material on top of the clays. And deep road cuts seem to prove that the clay deposit is much too thick to undulate over a still more uneven till and rock surface. It seems more likely that the surface was produced by sedimentation in contact with lingering areas of thin ice.

IMPLICATIONS OF THE THEORY OF DOWNWASTAGE.

Inasmuch as the features described here as characteristic of New Hampshire can be seen also in Maine and the Maritime Provinces and as the hypothesis of downwastage applies equally to all, the possible consequences of it are of more than local interest. Moreover they touch our conception of lateglacial crustal upwarping and of rates of rise of sealevel.

Why the "Marine Limit" is so Obscure.

The strange discontinuity and obscurity of strandlines at the upper limit of lateglacial marine submergence has been remarked by almost every investigator of the records, from Quebec and Nova Scotia down to Massachusetts. Search for emerged beaches and measurements of their elevations by the writer, begun in 1909 for the Geological Survey of Canada, extended up and down the St. Lawrence and Ottawa valleys, around the coast of Gaspé, New Brunswick, Prince Edward Island and Nova Scotia, and concluded in 1926, together with scattered observations on the coast of Maine and more detailed studies in southeastern New Hampshire and in Essex County, Massachusetts, have confirmed the opinion that true records of wave and shore-current action above the old seafloor deposits are not only scarce but impossible to distinguish from icemarginal deposits of stratified drift. A favorite theory to account for this obscurity of watermarks, namely, a rapid and uninterrupted emergence of the coast when uncovered by the ice has never been really satisfactory, in view of the probability that even on an emerging coast violent storms must occasionally leave strong strandlines at favorable places. The alternative theory of an ice-bound coast without effective wave action has been entertained by many writers, although the existence of shore ice so continuous and lasting for so long a time was not explained, and the only direct evidence of its presence seemed to be the removal of erratic boulders from the zone of emergence. If now we apply the theory that the ice sheet uncovered the coast by thinning down upon it, the lateglacial blanket of ice comes to have a new meaning, and the zone thus shielded from wave action acquires a breadth and degree of permanency that seems adequate.

Still we are left with the problem of reconstructing the waterplane of the lateglacial sea. To solve this we have a very limited number of what seem to be reliable shoreline features, built by waves and currents at sealevel, and mostly at or near the upper "limit"; less definitely and accurately we have the much larger number of watermarks presented by ice-marginal kames, washplains and embankments, with all their variety of form and structure. Their approximations to flatness at elevations not wholly out of accord with the accepted "beaches" and with one another, and their internal composition and structure, especially the unconformities that separate topset beds from foresets,—all these, if considered carefully as indicators of the local waterlevels to which they were related, may ultimately fix the position of the lateglacial sea as closely as we have until now thought it fixed. But until the record is more fully analyzed, it seems best to adopt the view that the southeastward gradient of these lines of lateglacial outwash is as much an initial slope of meltwater as it is an upwarped waterplane of the sea.

Ice Thinning as a Cause of Crustal Upwarping.

Both in North America and in Fennoscandia, studies of lateglacial upwarping have led to general acceptance of the theory that these crustal movements were caused by removal of ice load. Particularly in Fennoscandia the argument seems strong: for (a) the unwarped area is approximately the area formerly covered by ice; (b) the upwarping was greater where the ice was thicker, with a few low flattish domes of uplift simulating the former higher dome of ice which centered over the Baltic Sea; and (c) the uplift came promptly with ice recession, and proceeded fast for centuries. Though slowing down greatly, it seems to have continued even to the present time. The remarkable analyses of rates of recession of the ice border over Sweden by DeGeer and over Finland by Sauramo, together with the extraordinarily detailed studies of upwarped waterplanes by investigators of both countries present a strong case for this view of cause and effect. It has recently been reviewed by Daly.[37]

In North America Antevs' studies of ice retreat along lines of varved sediments in western New England and New York and in the Sudbury-Cochrane district of Ontario, filled out by rough estimates of longer time intervals during ice recession across the gaps that separate and lie beyond these lines, have renewed the emphasis on the classic theory of orderly ice recession, leaving almost unmentioned the probable lowering of the surface of the ice sheet by areal wastage. If thinning down of the ice proceeded so far as we are led to suppose it did in New Hampshire before the overspreading of the lowlands by sea or lakes, and if response of the crust to removal of load was as prompt as all have thought, then it seems likely that a large part of the crustal upwarping came before waterplanes were registered. Thus the total amount of uplift may be much greater than hitherto figured from the deformed shorelines of the lateglacial seas and lakes,—which adds to the difficulty of attributing so great a crustal movement to an ice sheet from 5,000 to 10,000 feet thick.

Ice Thinning and Rise of Sealevel.

Changes of sealevel accompanying the waxing and waning of ice sheets have been taken more and more seriously with fuller knowledge of the maximum areal extent of the ice caps and with more definite measures of their actual or minimum thicknesses. Antevs and Daly, particularly, have computed the vertical oscillations of sealevel or "eustatic changes" of the last glacial stage. Correct analysis of postglacial drowning of the coast, not only on opposite sides of the Atlantic but throughout the world is of wide consequence; for upon it may depend the proper correlation, for instance, of prehistoric human records in Europe and America. Also eustatic movements must be disentangled from regional crustal oscillations of lateglacial time, supposedly due to unloading. If it should appear that the amount of water delivered to the sea by ice melting during the decline of the ice age depended more upon downwastage of the surface than upon final recession of the ice margin, it is not easy to judge correctly the stage reached by rising sealevel for any given position of the ice border. If, for example, one wished to estimate the stage reached by rising sealevel when the ice uncovered Boston, it would be useless to figure out a ratio between the distance from Nantucket moraine to Boston and the total distance from Nantucket to the center of glaciation in Canada. Vertical and horizontal wastage may not have been at all proportional.

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[37] Daly, R. A.: The changing world of the ice age, New Haven, Chapters II, III, 1936.

CONCLUSION.

It was natural that glacial geologists in New England, impressed by the elaborate mapping of recessional moraines in the Great Lakes region for several decades, sought to interpret their own lateglacial records accordingly. So fully were our minds accustomed to the theory of a single great ice front across New England that there was danger of ignoring the downwastage that must have accompanied it. Sufficient thinning by ablation to produce lobes in the deeper valleys was conceded, indeed; but wholesale fragmentation of lingering ice masses was suggested only in rare instances, such as Clapp's study of Glacial Lake Charles. In New Hampshire, so long as detailed studies covered small areas and reconnaissance was handicapped by poorly contoured maps, it was easy to imagine correlations of hummocky moraine-like banks of drift, or of scraps of ice contact deposits found in lines transverse to ice flow, and to grasp at these eagerly as promising signs that the favorite theory would finally find full illustration in northern New England.

Especially when DeGeer's key to lateglacial chronology—the matching of varves—was skillfully applied to New England and Canada by Antevs in the early 1920's, previous doubts were all but forgotten and lines of ice front were plotted boldly across broad belts of hilly country from the Hudson to the Connecticut and from the Connecticut to the Merrimac. At last we had "aequicesses" like those drawn by DeGeer in southern Sweden and by Sauramo in Finland. But the gaps between these rivers were very wide, the terrain highly irregular, and the "moraine" fragments obscure and as yet little explored.

The first real challenge to the theory of orderly recession in New England came in 1929, when Flint held that the "recessional moraines" of this region were fictitious and that the deposits of western Massachusetts and Connecticut required stagnation and irregular downwastage of the ice.

During this interesting decade or two, all of New Hampshire has been freshly contoured, the State Highway Department's gravel survey has examined and mapped several thousand deposits, and an effort has been made to account for them, singly and collectively. Ice-contact features almost everywhere have proved to be irregular and to trend north, east, west or south, with little preference, instead of transverse to ice flow. Kame terraces arranged on opposite sides of valleys are the dominant type of stratified drift; and their persistence is remarkable. Associated kames of great variety of size and shape, and crevasse fillings, strengthen further the impression that in this hilly region we are not dealing with one continuous ice edge that receded in orderly fashion across country but rather with a maze of downwasting, thinning ice which lay stagnant or nearly so when these gravels and sands finally accumulated, occupying areas so utterly ragged in outline and so unstable in pattern that one can hardly reconstruct successive stages of ice removal on the maps.

Three lines of supposed halt and readvance in New Hampshire, plausible enough so long as reconnaissance followed selected zones and gave certain forms and structures false significance, have had to be abandoned as fuller mapping on the new quadrangles and study of many new exposures brought out the abundance of ice-marginal forms and showed their marked tendency to lie along lines of meltwater drainage, parallel to ice motion rather than transverse to it. Particularly this has been the case in the coastal region, where ice-molded kames and pitted plains run in parallel systems, seaward, as if directed by the evenly slanting surface of an ice sheet that had thinned down almost to sealevel but was traversed by parallel ice canyons.

These characteristics of kettled and ice-banked outwash material are not peculiar to New Hampshire alone; they prevail also in Maine, though not yet mapped in detail there. On the surrounding lowland the sag-and-swell surface of marine clay invites the idea that downwastage of ice continued even until the last fine sediments were spread. The obscurity of shoreline features at the marine limit may thus be explained. But in adopting this view of the lateglacial records we give up the long cherished basis for figuring accurately the amount of lateglacial upwarping.

Finally, in admitting downwastage as a large factor in the removal of ice from the surface of New England, we add an unrecorded amount of lateglacial deformation to what has hitherto been figured, and thus increase the difficulty of accounting for so much uplift by the removal of ice load. We also complicate the problem of timing the lateglacial rise of sealevel, since that may be less closely related to horizontal shifts of an ice margin than we have thought.

In spite of these disturbing consequences, it is the writer's slowly formed conviction that the evidence from New Hampshire and adjoining states favors the theory that ice removal here was accomplished largely by thinning.

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PARTIAL FUSION OF GRANODIORITE BY INTRUSIVE BASALT, OWENS VALLEY, CALIFORNIA.

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ABSTRACT.

Granodiorite adjacent to intrusive Pleistocene basalt has been partially vitrified through distances exceeding seven feet from the contact as the result of the selective fusion of quartz and feldspar, whereby an interstitial colorless glass of index 1.495 was formed.

Columnar granodiorite projects through the alluvium a few miles west of the town of Bishop, Owens Valley, California, a mile or so from where the canyon of Bishop Creek opens upon the alluvial fan at the foot of the Sierra Nevada. This remarkable exposure forms a large outcrop 200 feet long and 25 feet high, alongside of the paved highway to Bishop Canyon. The columnar structure in the granodiorite is manifestly a thermal effect of an irregular shaped intrusive mass of olivine basalt, which is locally 50 feet thick and has sent off irregular apophyses into the granodiorite. Astonishingly, the basalt is without columnar structure, but the granodiorite adjacent to it has a conspicuous development of columns. These columns are from four to seven feet long and average a foot in thickness. They are roughly four, five, and six-sided; they are normal to the contact at the contact surface, but many are curved, some bending from horizontal to vertical. The columnar structure was shown to be a consequence of the formation of interstitial glass throughout the granitic rock as the result of heat supplied by the intrusive basalt, which is probably of Pleistocene age.[1] This interesting exposure is now much more easily accessible than it was in 1913 when the writer first examined it; and in June, 1936, he was able to revisit it by automobile instead of on horseback and to make additional study of it.

The basalt near the granodiorite contains innumerable inclusions consisting of feldspar and quartz fragments and pieces of granite ranging up to blocks several feet in diameter. Locally the feldspar fragments are so evenly scattered through the basalt that the basalt resembles a highly feldsparphyric andesite.

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[1] Knopf, Adolph: A geologic reconnaissance of the Inyo Range and the eastern slope of the southern Sierra Nevada, California: U. S. Geol. Survey Prof. Paper 110, pp. 74-75, 1918.

The most nearly normal basalt that could be found is an aphanitic rock containing about ten per cent of small olivine phenocrysts. Some augite phenocrysts also occur, and these minerals are embedded in a groundmass made up predominantly of augite microlites, together with plagioclase microlites (An_{60}), glass, and magnetite grains. A few xenocrysts occur: biotite largely altered to magnetite, and feldspar and quartz surrounded by coronas of augite prisms, so that even the most normal-appearing basalt has been somewhat contaminated.

Basalt that contains abundant xenocrysts has much clear brown glass, of an index notably less than that of balsam, being 1.505 in the specimen measured. The feldspar xenocrysts strikingly show peripheral invasion or more generally pervasive honeycombing by brown glass, whereby a curious shagreened effect has been produced. Some feldspars, to use Lacroix's expressive phrase, show demolition into small rectangular solids as the result of the heat having opened the (001) and (010) cleavages and allowing the glass to penetrate along these openings.[2] The quartz xenocrysts have been vigorously embayed by brown glass—in places circular patches of brown glass appear in the central portions of the xenocrysts, the glass evidently having bored its way in from below or above the plane of the thin section. The glass that has embayed the quartz commonly incloses abundant tridymite, which shows sectorial twinning in the platy sections and forked ends in the lath-shaped sections. The tridymite, of course, has a much lower index than the glass in which it is embedded, and the glass itself has a much lower index than the quartz. No tridymite was seen that could be attributed to inversion of the quartz.

No unaltered granodiorite was found, all the specimens collected showing on microscopic examination that they have been partly vitrified. The original unaltered granitic rock appears to have been a granodiorite in which andesine (An_{35}) predominated over orthoclase. The dark mineral, which amounted to about ten per cent, probably in the main biotite, is greatly altered to a mixture of magnetite, spinel (?), and red biotite; in fact the original biotite is nearly pseudomorphosed by magnetite. No evidence of fusion of the biotite was found; in this failure to melt, the biotite has behaved differently from that regarded as normal by Lacroix and Harker, who think that biotite in granite is the mineral most easily affected, yielding a brown glass, which recrystallizes with extreme facility into spinellids, hypersthene, and other minerals. Day and Allen, however, found that on thermal treatment at atmospheric pressure in the laboratory a granitic biotite became at 650° C. reddish and biaxial, and above 900° C. it decomposed rapidly with the formation of magnetite.[3] Possibly at high pressure biotite would melt to a glass. The indications are therefore that the granodiorite was vitrified at relatively low pressure.

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[2] Lacroix, A.: Les Enclaves des Roches Volcaniques, p. 572, 1893.

Some of the columnar granodiorite contains enough glass to make it resemble a porphyry having a sparse glassy groundmass. Such rock, as measured on the hand specimen, has the low specific gravity of 2.49, in part because of the abundance of glass and in part because of the vesicular state of the glass. Under the microscope the glass is seen to be clear and colorless—as colorless as the adjacent quartz, and to be completely isotropic. It contains a minor amount of round vesicles, some of which are filled with chlorite. Perlitic cracking is common, especially near the vesicles and around inclusions of zircon. The glass locally incloses multitudes of minute prisms, ranging from hairlike fibers to small stout columns. The larger prisms have long forked ends, positive elongation, straight extinction, moderate birefringence, red pleochroism, and indices slightly greater than 1.68; the mineral is therefore identified as hypersthene. The only analogous occurrence known to the writer is one described by Rinne[4]: sandstone xenoliths inclosed in basalt have been melted to a clear glass, and in certain thin sections many hundreds of skeletal crystals of hypersthene are crowded together, many of them of remarkable forms, as is well shown in Plate V of Rinne's paper.

The glass is obviously localized around the quartz grains of the granodiorite, forming an envelope around them, and appears to have formed mainly along the contacts with the orthoclase. Contacts of the glass are smooth and rounded, and the quartz grains especially have a corroded or "resorbed" appearance. The quartz, unlike normal granitic quartz, is conspicuously crackled. The orthoclase has not been sanidinized, although Lacroix found in the xenolithic granites he studied that the orthoclase had become nearly uniaxial or of small 2V in the plane 010 (*orthose déformée*).[5]

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[3] Day, A. L., and Allen, E. T.: The volcanic activity and hot springs of Lassen Peak, p. 49, 1925.

[4] Rinne, F.: Ueber rhombischen Augit als Kontaktprodukt: Neues Jahrbuch, Vol. 2, p. 229, 1895.

The colorless glass, on examination in immersion oils, proves to have an index of 1.495—about that of a silicic rhyolite glass. This index, together with the evident localization of the glass around the quartz, warrants therefore the conclusion that the glass was produced by mutual reaction between the quartz and the adjacent feldspar, forming a relatively low melting liquid. The liquid thus formed appears to have dissolved some of the biotite, as suggested by the greater abundance of hypersthene needles and prisms in the glass near the relicts of altered biotite. It can be seen from the foregoing description, that the selective fusion phenomena shown by the partially vitrified granodiorite of Owens Valley conform with the facts experimentally established in the Geophysical Laboratory in Washington,[6] namely that quartz and alkali feldspars form the lowest melting liquids, much lower than would be anticipated from the high melting points of the individual constituents.

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[5] Lacroix, A.: Op. cit., p. 571.

[6] Goranson, R. W.: Some notes on the melting of granite: This Journal, Vol. 23, pp. 227-236, 1932.

Bowen, N. L.: Recent high-temperature research on silicates and its significance in igneous geology: This Journal, Vol. 33, pp. 1-21, 1937.

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TWO YOUNG MERYCOIDODONTS.

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ABSTRACT.

Two skulls of young merycoidodonts in the Amherst Museum collections present some interesting features hitherto unrecorded. One belongs to a foetal individual and is remarkable in clearly showing such characters as a fontanelle, open sutures, and a very incomplete dental series. The other specimen demonstrates the order of tooth replacement, and is further of interest because of problems in connection with species determination.

PROMERYCOCHOERUS cf. THOMSONI Loomis 1924.

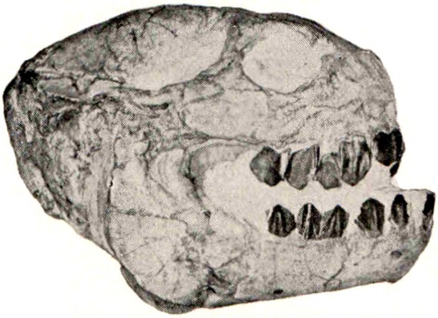
Plate I, Figs. 1-6.

Promerycochoerus thomsoni Loomis, Bull. Amer. Mus. Nat. Hist., 1924. LI, Art. 1, pp. 22-23, Figs. 10-11.

This specimen (Amherst Museum Cat. No. 1935-28) was not found in place by a collecting party of the college, but was purchased by Mr. J. W. Harlow of the Amherst College staff near Manderson, South Dakota. It is probable that its age is Lower Miocene, since it was allegedly obtained from the Rosebud beds.

The characters present in this skull warrant its being identified as a foetal individual. Preservation of such an individual is an unusual occurrence because of the delicacy of the bone. The skull bones are very thin and were undoubtedly soft; considering these facts the specimen is in an excellent state of preservation. It has been preserved because it was enclosed in a hard concretion which must have formed relatively soon after the death of the animal, before any significant thickness of sediments was deposited on it, since the bones of the skull are not appreciably crushed. It is likely that the mother died while her young was yet unborn, although we have no knowledge of an adult specimen associated with this specimen.

Description. Skull small, with very thin bones. Nasal bones and muzzle lacking; but from the angle at which the upper tooth rows approach each other it may be inferred that the muzzle was short, and the length of the ramus bears out this conclusion. Braincase relatively very large and wide, occupying about half the skull length and most of the width. Orbits fairly large, round, and facing laterally. Roof of skull



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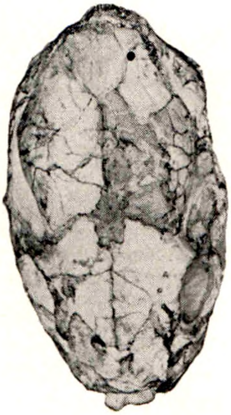

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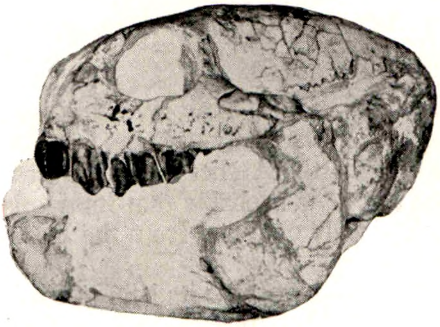

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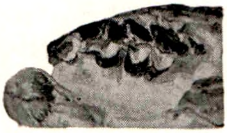

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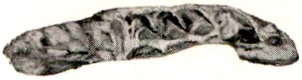

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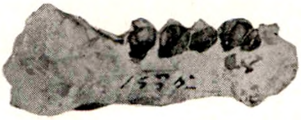

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PLATE I.

Fig. 1. Side view of skull of *Promerycochoerus* cf. *thomsoni.*
Fig. 2. Same.
Fig. 3. Superior view of skull.
Fig. 4. Right superior dentition, occlusal view.
Fig. 5. Left inferior dentition, occlusal view.
Fig. 6. Same, lateral view.
All illustrations are natural size.

smooth, with no crests as in adult forms; there is a short, blunt extension over the occiput. The occipital condyles and foramen magnum can be seen on a line approximately horizontal with the upper tooth row. Zygomatic arches somewhat crushed and broken; a reconstruction of the zygomatic arches on the basis of the position of the malar, which is very close to the main body of the skull, indicates that they extended laterally not more than 4 mm. from the braincase.

The sutures between the skull bones are all open, the most widely open being those between frontals and parietals. At the junction of the longitudinal median suture of the skull with the fronto-parietal suture there is a small opening where the bone is somewhat broken away. The position of this opening and the thinness of the bone at this place indicate without a doubt that the individual had a fontanel. Other sutures which can be seen clearly are those between the temporal and squamosal, between the interparietal and parietal, between the malar and zygomatic process, between the lacrimal and the maxillary and premaxillary, the symphysis of the ramus, and the sagittal suture running the length of the skull.

The infraorbital foramina lie above a point between dP^3 and dP^4.

Six teeth in the upper jaw and seven in the lower are erupted. No incisors are present and there is not sufficient space to accommodate all the frontal teeth. The teeth present are dC_1, dP_2, $dP\frac{3}{3}$, $dP\frac{4}{4}$, and dM^1. Only one dC_1 is present; it can be identified as a canine by its peg-like, incisiform shape (merycoidodont lower canines are modified to function as incisors), and by its position in the jaw. The long axis of this tooth is lateral instead of antero-posterior as in the cheek teeth. The frontal space between the upper tooth rows, which would eventually accommodate one other premolar as well as a canine and three incisors on each side, is only 6.5 mm. The corresponding space in the lower jaw, which must accommodate the incisors, measures only 5.5 mm. The only conclusion which can be drawn from these facts is that considerable lateral and longitudinal growth of the jaw and muzzle would be neccessary before the complete deciduous dentition could be erupted.

In comparison to the size of the skull the dentition appears brachyodont. The teeth are very sharp and completely unworn. A description of the individual teeth is as follows:

dC_1. A peg-like tooth, longer and slightly more narrow than the other teeth present in the lower jaw. About the same shape as the incisors in an adult specimen and of C_1 which is incisiform in appearance and position.

dP_3. With a sharp primary cusp, and apparently lacking the anterior crest and crescent. Posterior to this cusp the posterior crest and crescent diverge laterally. These occupy the posterior third of the tooth, and their posterior ends are 3.5 mm. apart.

dP_4. Three pairs of unworn molariform cusps; crests flat, slim. A very long tooth in comparison with the others, widening slightly posteriorly.

dP^3. Posterior crest of primary cusp much longer than anterior crest; posterior crescent bulging more toward the median line than anterior crescent; anterior intermediate crest very weak. On both sides of the upper jaw this tooth is set at an angle of approximately 45 degrees to the rest of the tooth row, pointing toward the median line of the skull.

dP^4. Two sharp crests, with the anterior one a little longer. Branching off from the anterior crest is a short anterior intermediate crest. The anterior crescent is narrow but the posterior crescent is wide, being of approximately the same dimensions as the crescents of the molar posterior to it. Tooth triangular, being narrow anteriorly and wide posteriorly.

dM^1. Crests narrow, flat rather than curved. The posterior crest overlaps the anterior one considerably, and the anterior crest overlaps the posterior crest of dP^4. The points of the crests are broken off but they were probably quite sharp.

In addition to these fully erupted teeth there is visible in the left upper jaw posterior to dM^1 the point of a tooth which is just beginning to appear through the bone. This is probably dM^2. Tooth roots have been excavated in the bone posterior to dP_4 on both sides of the lower jaw. These are probably the roots of unerupted dM_1. On the left ramus, anterior to dP_2 the bone is broken and a tooth can be seen on the point of eruption. This tooth is similar in shape and position to the dC_1 present in the other ramus.

Discussion. The specimen at hand is assigned to *Promerycochoerus* cf. *thomsoni* Loomis on the basis of the dentition, since the immature characteristics of the skull show such great variation from any adult form. dM^1 has proved most useful (the only molar present in this specimen). This tooth has a very distinctive shape: each crest has a strong anterior style which overlaps the crest anterior to it. Aside from these styles, which stand out conspicuously from the surface of the tooth, the tooth crests are only slightly curved, and are produced in a sharp point on the occlusal surface. All these characters also occur in M^1 of an adult *P. thomsoni* and have been found also in the deciduous teeth of a known young specimen of *P. vantasselensis* Peterson (1906). Another point of resemblance between these known young specimens and the one at hand is the shape of the tooth row, which slants upward and slightly inward posteriorly.

The only published treatment of a foetal merycoidodont skull known to the authors is that of C. C. O'Harra (1930). This is of the skull of a foetal *Merycoidodon culbertsoni* "found lying within the pelvic girdle of an excellently preserved skeleton." The circumstances under which O'Harra's specimens were discovered leave no doubt that they were unborn individuals. Comparison of the specimen at hand with R. Bruce Horsfall's figures of one of these young merycoidodonts (Thorpe, 1937) shows striking similarities between the two. The most obvious similarity is the peculiar shape of the supraoccipital bone, which is blunt and extends very little over the occipital condyle. The shape of this bone has very interesting implications. Young individuals of two different genera possess this type of supraoccipital while the adults of both have crests which are produced posteriorly and terminate in more or less flaring "wings." Such marked changes as these, taking place as the animal grows to maturity, make definite generic classification of a young specimen very difficult, and tooth pattern is the only useful criterion.

Other likenesses between the two foetal specimens are the number of teeth (the same except for the missing canines and incisor in the *Promerycochoerus*), the open condition of the sutures (which are a little more open in *Promerycochoerus*), the broad braincase, and the light zygomatic arches.

In spite of its many similarities with O'Harra's specimen this individual is certainly younger. Its sutures are more open; although the teeth show *Promerycochoerus* characters the skull is no larger than that of the *Merycoidodon* foetus (an adult *Promerycochoerus* is much larger than *Merycoidodon*); also, dM_1 has not erupted in the present specimen. All these facts show conclusively that the animal died before it was ready for birth.

In order to study further the changes which occur in the skull between the foetal and the adult stages, a comparison was made between the skull of a foetal pig (two weeks before birth) and that of an adult form. This was done not because of any assumed close relationship between the Suidae and the

Merycoidodontidae, but because foetal pig material was readily available. Many parallel changes between the foetal and adult forms were observed. One of the most striking of these is the appearance of a well-developed supraoccipital crest in the adult, there being no sign of one in the foetus. In both of the foetal pig skulls which were examined there occurs a fontanel at the junction of the median and fronto-parietal sutures, the bone being thinnest and very soft around this area. Also, the relative size of the braincase is vastly greater than in the adult. In the foetal form of the pig and of *Merycoidodon culbertsoni* the muzzle is much less prominent than in the adult of either form; this was also probably true in the case of the *Promerycochoerus* foetus. The adults of all these forms have much longer muzzles to accommodate the longer tooth rows of the permanent dentition. These parallel developments emphasize the fact that the differences between foetal and adult forms are not confined to a single group of mammals but are more or less generalized.

MEASUREMENTS.

	Mm.
Length of skull . . . Approx.	52
Basal length of skull (anterior end of ramus to posterior end of occipital condyle)	51
Postorbital constriction diameter	20
Braincase diameter	24
Width between middle of orbits	17
Anterior-posterior diameter of orbit	10.5
Vertical diameter of orbit	9.5
Depth of malar below orbit	6.7
Ramus:	
Maximum length	42.5
Symphysis length	6.5
Depth, coronoid to angle	23.5
Depth below dP_4	8
Dentition:	
Superior dentition length	20
Superior premolar series length	10.5
dP^3 anterior-posterior diameter	6
transverse diameter	4
dP^4 anterior-posterior diameter	7.5
transverse diameter (anterior lobe)	4.8
(posterior lobe)	6.8
Inferior dentition length	22.5
dC_1 anterior-posterior diameter . . . Approx.	3
dP_2 anterior-posterior diameter	4
transverse diameter	3.5
dP_3 anterior-posterior diameter	5
transverse diameter	4.5
dP_4 anterior-posterior diameter	11
transverse diameter (anterior lobe)	4
(posterior lobe)	5.5
(median lobe)	5

MERYCOIDES cf. CURSOR Douglass 1907.

Plate II, Figs. 1-4.

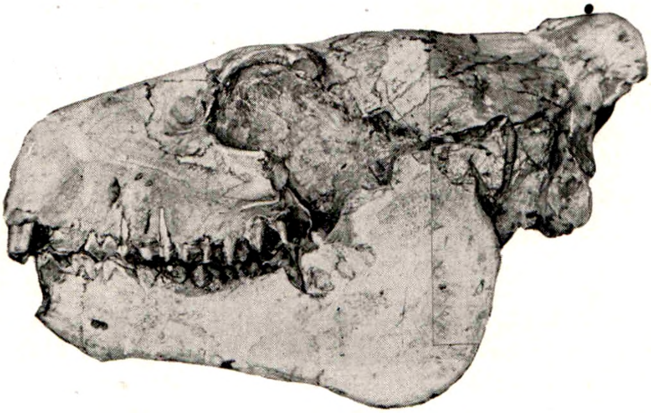
Merycoides cursor Douglass, Ann. Carnegie Mus., IV, 1907, pp. 101-102, Pl. 24.

A skull of a young individual of *Merycoides* (Amherst Museum Cat. No. 22-14) was discovered by Prof. F. B. Loomis in 1922 at Arnold Ranch near Scenic, South Dakota, and is probably Upper Oligocene in age. It consists of the skull and mandible, and is in excellent condition except for the zygomatic arches which are broken away on both sides. In this study especial attention is given the dentition, which is considered with the purpose of determining the order of replacement of the deciduous dentition by the permanent dentition.

Description. Skull mesocephalic, massive as compared to young skulls of other genera (i. e. *Merychyus harrisonensis*), fairly broad, low, with inflated muzzle. Little can be ascertained concerning the zygomatic arches, since they are broken off on both sides, but the malar appears to be fairly sturdy below both orbits. There are no facial vacuities. Nasals unreduced, obtuse and serrate. The lacrimal bone lies almost entirely in advance of the orbit; lacrimal fossae deep and large. Frontals large, unreduced, and slightly concave toward the suture between them, extending 7 mm. in front of the lacrimals. Orbits large, apparently nearly circular; they appear to look forward as well as outward. Temporal ridges low, very faint, uniting over the glenoid surface to form a short and rather low sagittal crest. Supraoccipital crest overhanging the occipital condyles, with wings quite widespread. Braincase low and laterally inflated. External auditory meatus not easily observed in this specimen, but apparently pointing outward and backward, and situated above and just posterior to the glenoid surface. Basicranial axis quite steep. Both paroccipital processes broken at the ends, but appearing triangular in outline, short and fairly heavy, behind and in contact with the surface of the bullae. Bullae very large and subovate in shape. Cephalic index roughly .53.

Chin sloping downward and backward at an angle of about 40 degrees from the premolars; inferior angle of the chin well marked. Lower border of the ramus nearly straight to a point just below the unerupted M_3, ascending gradually to the angle. Massateric fossa fairly large. Symphysis open.

The infraorbital foramina are above the interval between P^2 and dP^4. The supraorbitals lie on a plane approximately



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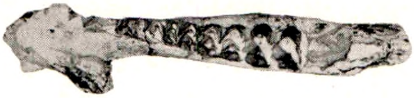

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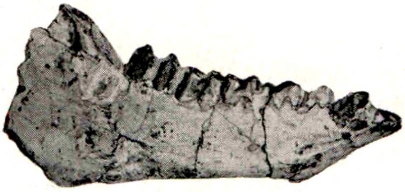

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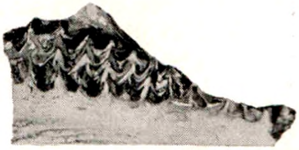

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PLATE II.

Fig. 1. Lateral view of skull of *Merycoides* cf. *cursor*.
Fig. 2. Occlusal view of right inferior dentition.
Fig. 3. Lateral view of right dentary, showing dentition.
Fig. 4. Occlusal view of left superior dentition.
All illustrations are half natural size.

through the center of the orbits, fairly close to the median suture. The other foramina cannot be seen due to the condition of the skull.

This individual probably had 40 teeth erupted at the time of its death. There are 17 teeth in the upper jaw, with two unerupted molars. The incisors have been lost along with the premaxillary, but it may be safely assumed that there were six. The tooth replacement would add one more premolar to this dental series.

Matthew (1901) gives the order of replacement of deciduous cheek teeth by permanent ones in merycoidodonts as follows: $M\frac{1}{1}$, P^1, $M\frac{2}{2}$, C^1, P_1, $I\frac{1}{1}$-$\frac{3}{3}$, C_1, $P\frac{2}{2}$-$\frac{4}{4}$, $M\frac{3}{3}$. The teeth of this specimen are considered in this order.

M^1. Certainly a permanent tooth. Occlusal surface moderately worn. The anterior and posterior crests and crescents are about the same length.

M_1. Occlusal surface slightly worn. Distinctly higher crown than in the premolars.

P^1. Undoubtedly permanent, judging from the height of crown and condition of wear.

M^2. Permanent. A large, high crowned tooth which has come to the level of the grinding surface but is only slightly worn.

M_2. Permanent. Very little wear.

C^1. Broken, but from what can be seen they appear sturdy enough to be permanent teeth.

P_1. Badly broken but probably permanent.

$I\frac{1}{1}$-$\frac{3}{3}$. Not present. Lower broken off at jaw level.

C_1. Broken off at jaw level.

P^2. Large size, little worn. Permanent.

P_2. Smaller than P^2. Much worn. Deciduous.

P^3. Not yet erupted. Space to be provided for its eruption by the shedding of dP^4.

P_3. Small and much worn. Deciduous.

P^4. Considered deciduous because of relative wear on the occlusal surface. Two-lobed with the forward lobe having an arrangement of crest and crescent like those of the two premolars anterior to it, but wider laterally. The posterior lobe has a distinctly molariform crest and crescent. The resultant shape in the occlusal view is a triangle with the apex forward.

P_4. Considerably worn; deciduous. A three lobed, molariform tooth with the three lobes increasing very slightly in size posteriorly. Only about half as high in the crown as the two permanent molars posterior to it. This tooth has three crests and three crescents resembling those of the permanent molars, but the ridge running vertically from the point of each inner cusp of the permanent molars to the point where the tooth emerges from the ramus seems to be lacking.

M^3. Large, sharp, apparently newly erupted. Permanent.

M$_3$. Unerupted; roots present in ramus.

Discussion. In the description of a young form such as this one, the most important feature in determining the relative stage of growth is in the teeth. In this case it is certain that M$\frac{1}{1}$, P^1, M$\frac{2}{2}$, P^2, and M^3 are permanent. The only teeth which are considered deciduous are P^4, and P$_{234}$, on the basis of relative wear and shape as indicated by Loomis (1925A). The only conclusion which can be drawn from the presence of dP$\frac{4}{4}$, after the eruption of M^3 and before the eruption of M$_3$ is that eruption of the third molars must occur at the same time or before the replacement of the milk premolars. Judging from this specimen, the latter part of Matthew's order of tooth replacement should be revised to make the order as follows:

M$\frac{1}{1}$, P^1, M$\frac{2}{2}$, C^1, P$_1$, I$\frac{1}{1}$-$\frac{3}{3}$, C$_1$, P^2, M^3, P$\frac{3}{3}$-$\frac{4}{4}$.

Since both P^2 and M^2 are fully erupted it is impossible to tell from this specimen alone which of these teeth should appear first in the replacement order. M$_3$ and the permanent premolars (except P$\frac{2}{2}$) being unerupted, we cannot be absolutely certain which would appear first. In this case, however, M$_3$ seems quite close to eruption while there is no indication of the imminent eruption of the permanent premolars other than those already present.

In order to accommodate M$_3$ the lower jaw would need to increase in length the length of the unerupted M$_3$, or about 16 mm. In this case occlusion with M^3 would not be possible until M^3 were forced posteriorly about 8 or 10 mm. It would then be necessary for the upper cheek teeth and the anterior portion of the skull to lengthen that amount. This would provide a position for the additional premolar in the upper series (probably P^3), thus making the length of the two tooth rows almost equal and bringing the total number of teeth to 44. It appears likely that M$_3$ would erupt before the upper jaw had elongated sufficiently to allow the eruption of the other permanent premolars.

The open state of the sutures in this specimen confirms the evidence of the dentition that it was quite young at the time of its death.

The skull is referred to *Merycoides* for the following reasons: presence of deep lacrimal fossae and very large bullae, and lack of facial vacuities. Secondary considerations are the moderately large and mesocephalic skull, the unreduced frontals, the rather slender mandible, and the fact that the face occupies more than half the total length of the skull.

M. longiceps (Douglass) (1907) from the Upper Miocene differs from this specimen in the presence of facial vacuities. The specimen at hand resembles both *M. cursor* and *M. latidens* (Douglass) (1907) but is thought to be more closely allied to the former species. It resembles *M. cursor* especially in having an inflated muzzle, inflated bullae, and a symphysoidental angle of about 40 degrees. It differs from *M. cursor*, however, in a few rather striking respects: the nasals are obtuse and serrate posteriorly instead of being pointed, and the wings of the supraoccipital crest are widespread instead of being close together. These points of difference from *M. cursor* are also the important points of similarity between this specimen and *M. latidens*. A comparison of the specimen with the plates of the two species (Thorpe 1937) shows the conformation of the skull and the relationships of the various parts to be somewhat closer to *M. cursor*.

It is not possible to determine whether this specimen should be assigned to a new species because of its youth. It is perhaps possible that the major differences separating it from *M. cursor* would disappear as the animal attained maturity. Matthew and Cook (1909) state that none of several young specimens of *Metoreodon profectus* showed the typical characters of the species. They were forced to content themselves with the fact that more diagnostic characters of this species were shown than of any other. This would indicate that young individuals are more or less generalized in their characters; it also demonstrates that there is probably no sharp break between the species of any genus. With these probabilities in mind a very interesting problem could be found in the study of the morphological changes between the generalized condition of the young and the comparatively specialized characters of adult individuals. Such changes as the growth of the supraoccipital crest and the drawing together of its wing-like projections are most striking.

MEASUREMENTS.

		Mm.
Maximum length	Approx.	170
Basal length (occipital condyle to end of muzzle)	Approx.	140
Bizygomatic diameter	Approx.	80
Postorbital constriction diameter		31.5
Braincase diameter		47.5
Width between middle of orbits		51
Orbits vertical diameter		25.5
Malar depth below orbit		12.5
Bulla anterior-posterior diameter		19
Bulla transverse diameter		14
Ramus maximum length		122
symphysis length		31
depth coronoid to angle		59.5
depth below M_2		26.3
Superior dental series with C		70
Superior molar series		37.5
Inferior molar series		26

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FOSSIL TERMITE PELLETS IN OPALIZED WOOD FROM SANTA MARIA, CALIFORNIA.

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ABSTRACT.

Small elongate objects with hexagonal cross-sections in opalized wood from the Pliocene of Santa Barbara County, California, at first interpreted as opal pseudomorphs after euhedral quartz crystals, prove to be opalized termite pellets. Associated with the opal is lussatite, originally described as a distinct form of silica, but here shown to be an intimate mixture of chalcedony and opal.

Fossil termite pellets were first reported by the writer[1] in a general paper on silica minerals. Since then Light[2] has called attention to termite pellets from the Seminole beds of the Pleistocene near St. Petersburg, Florida.

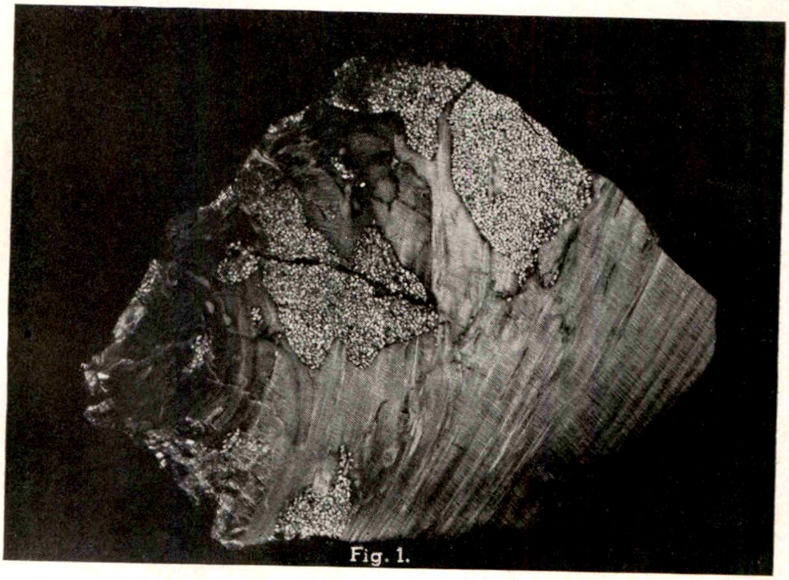

Fig. 1.

Fig. 1. (Natural size.) Polished surface of opalized wood with areas of termite pellets from Santa Maria, California. (Photographed by Alexander Tihonravov.)

I am indebted to the late James Perrin Smith for the specimen of opalized wood reproduced in Fig. 1. It was collected near Santa Maria, Santa Barbara County, California, from the Fernando (Pliocene) formation. The specimen is a typical cream-colored wood opal with greasy luster and rather low specific gravity. The main opal of the specimen has about the same hardness as a knife blade. When heated in a closed tube it gives off water. It is colorless in fragments and dark between crossed nicols with $n = 1.453 \pm .003$. Cell structure is well shown in both the hand specimen and the thin section. According to my colleague, Dr. LeRoy Abrams of the Natural History Museum, the wood was that of a conifer.

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[1] *American Mineralogist*, 13, 86, Plate V, Fig. 20, 1928.
[2] *Univ. Calif. Pub., Bull. Dept. Geol.*, 19, 75-80, 1930.

A prominent feature of the specimen is the presence of irregular areas in which the cell structure of the original wood is absent. These were recognized as the work of woodborers of some sort. Thin-sections of these areas are shown in Fig. 2.

These structures vary from longitudinal sections with rather rounded ends to cross-sections which are more or less hexagonal. The cross-sections vary from rounded and irregular outlines to almost perfect regular hexagons which are sometimes indented.

The hexagonal cross-sections such as are shown in Fig. 2 suggested euhedral quartz crystals and the writer at first interpreted the structures as opal pseudomorphs after quartz.

Although transformations of one silica mineral to another are well known,[3] the replacement of quartz by opal is very improbable, since it involves the change of a stable crystalline mineral to an unstable amorphous mineraloid.[4] It is true that a few crystalline minerals such as allanite, gadolinite, zircon, and thorite have sometimes been altered to amorphous substances which Brögger called metamict (metamikt). These contain rare earth or radioactive elements and the secondary isotropy is due to radioactive emanations which have destroyed the space lattice, according to V. M. Goldschmidt.

Fortunately the writer looked into the matter before publishing his results. The specimen of opalized wood was shown to my colleague, Dr. Harold Heath of the Hopkins Marine Station, who recognized the structures of Fig. 2 as termite pellets. Dr. Heath gave me some recent termite pellets from Pacific Grove, California, which show more or less hexagonal cross-sections. Another colleague, Dr. Hubert G. Schenck, presented me with a tube of recent termite pellets from the Philippine Islands. They show the same hexagonal cross-sections.

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[3] Sosman: *The Properties of Silica*, p. 60, Chemical Catalog Co., New York, 1927.

[4] The term mineraloid is used by the writer in his *Introduction to the Study of Minerals*, 3d ed., pp. 208, 262, and 575, New York, McGraw-Hill, 1937, for such substances as opal, cliachite, limonite, collophane, palagonite, volcanic glass, amber, etc., which are to all intents and purposes amorphous and show more variation in physical properties and chemical composition than do minerals proper.

It seems that the hind-gut of the termite has a hexagonal cross-section. The partially digested pellets have about the same composition (cellulose + lignin) as the original wood and so are as easily replaced by silica as the wood itself.

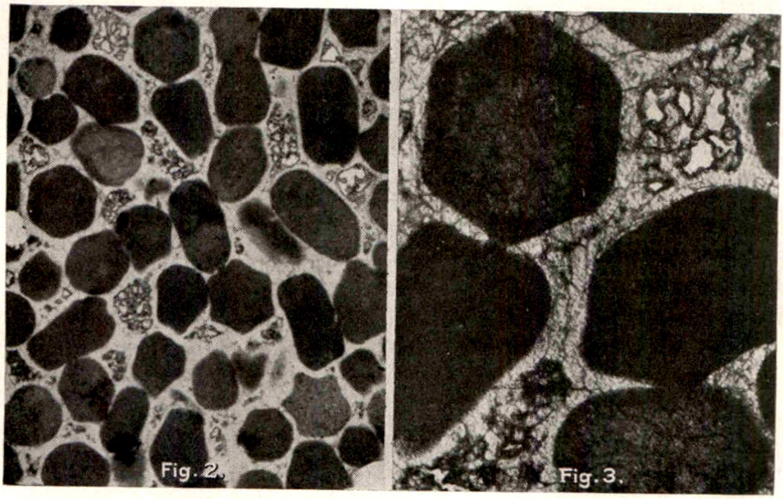

Plate II. Fig. 2. (x 15). Thin section of opalized termite pellets from Santa Maria, California. (Photographed by Dr. Welton J. Crook.)

Fig. 3. (x 45). Enlarged view of upper part of the thin section of Fig. 2, showing opalized pellet of hexagonal cross-section and interstitial opal with colloform lussatite.

The pellets of the fossil wood of the Santa Maria occurrence vary in length from 0.7 to 0.9 mm and in cross-section from 0.3 to 0.5 mm. The pellets also consist of opal, but this opal is cloudy and not as homogeneous as the main opal with the cell structure. The opal of the pellets is dark between crossed nicols and has an index of refraction of about 1.45.

In the neighborhood of the pellets, the wood structure is somewhat distorted. The curvature of the wood structure around the pellets was evidently due to the pressure exerted upon the wood fibers by the pellets.

The interstices between the pellets are occupied by opal which is more transparent than the opal of the pellets. In this interstitial opal there is occasionally found, in what were once cavities, a substance with high relief and small colloform[5] structure, as shown in Fig. 3. The colloform material when examined with an 8-mm objective exhibits a spherulitic structure with length-slow[6] fibers, and, since it has high relief with $n = 1.45$, it answers the description of lussatite, which was described by Mallard[7] as a new form of silica. Lussatite is listed as "tridymitoid chalcedonic silica" by Sosman,[8] but in the opinion of the writer[9] it is simply opal with embedded fibers of chalcedony. In all probability this is opal in process of change to chalcedony. I have also found spherulitic lussatite in chalcedony from Carmel, California, collected by Mr. Robert Elgin.

The only other mineral present and the last one to be formed is chalcedony, which is a cavity-filling in the lussatite areas. The chalcedony has such very low relief that it has the appearance of open spaces, but with crossed nicols it shows spherulitic structure with length-fast fibers.

Although three kinds of opal are present—wood opal, pellet opal, and interstitial opal—they are all of the same generation and there is no evidence of more than one stage of opalization.

According to Handlirsch[10] the first record of fossil termites is from the Eocene of Monte Bolca, Italy. Oligocene and Miocene forms are also recorded, as well as a few from the Pleistocene, but no mention is made of Pliocene termites. The Santa Maria occurrence is apparently the first report of termites from the Pliocene.

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[5] The term colloform was coined by the writer (*Jour. Geol.*, 25, 518, 1917) for the rounded, more or less spherical forms assumed by substances of colloidal origin in open spaces. It takes the place of the older terms, mammillary, botryoidal, reniform, etc.

[6] This convenient term of J. W. Evans is used for crystals with positive elongation.

[7] *Bull. Soc. Fr. Min.*, 13, 63-66, 1890.

[8] *Op. cit.*, p. 156.

[9] *American Mineralogist*, 13, 77, 1928.

[10] *Die fossilen Insekten und die Phylogenie der rezenten Formen.* Leipzig, 1906-8.

STANFORD UNIVERSITY,
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SCIENTIFIC INTELLIGENCE.

PHYSICS.

Through Science to Philosophy; by HERBERT DINGLE. Pp. 357; 18 figs. Oxford, 1937 (The Clarendon Press, $5.00).—One frequently hears comment to the effect that a scientist writing about philosophy falls in the category of a specialist writing outside his own field, with no authority, and that therefore his words should be ignored or even shunned as dangerous. Without going into a discussion of this point of view as a general principle it may be stated that it is becoming increasingly difficult to maintain such an attitude in the special case named. Certainly both scientists and philosophers, though mutually critical, are more and more yielding to the urge to express themselves in this way. If any of the aforesaid disciples of authority have not realized that the union of science and philosophy can furnish fascinating material and also that among the ranks of scholars in each study there are extremely able writers, they should by all means read the present book. Written by an astrophysicist, the approach, as the title implies, is scientific, mainly that of physics. Simply, directly and without apology the author states his personal philosophy of science. His view is solipsistic. In forming a unified conception of the history of science up to the present, he is logical and consistent, and offers an excellent explanation of the well-known perplexities of recent physics. At the risk of misinterpretation in so brief a summary, it may be stated that these perplexities are, in the author's opinion, based upon a failure properly to distinguish between "common-sense" and "scientific" reasoning. Both kinds of reasoning are legitimate, but were devised for different ends, and neither should be considered supreme, or uniquely true. It is not for this reviewer to comment on his evaluation of certain schools of psychology and philosophy; such criticism is given briefly and with due modesty, and it is felt that the points raised call for answers.

The first part of the book is occupied with the statement and clarification of the author's ideas with regard to the philosophy of science. Part II is devoted in the main to a discussion of the bearing of his views on recent moot questions in philosophy and in physics, such as the rôle of unobservables, the nature of time, the universe, causality, and the latter's inevitable companion, indeterminacy *versus* free will. Among these topics he seems on more precarious ground—at any rate in some he is less complete and less convincing. Nevertheless it must be admitted that his remarks are to the point, and in disagreeing with the views of others, as for instance Eddington, his is apt to be the broader, more comprehensive outlook. The book is eminently readable, the style is delightful, and in clarity of expression it is indeed hard to surpass.

A. T. WATERMAN.

CHEMISTRY.

Biochemistry for Medical, Dental and College Students; by BENJAMIN HARROW. Pp. 383; 52 illustrations. Philadelphia and London, 1938 (W. B. Saunders Co., $3.75 net.)—In this book Doctor Harrow has written a brief account of animal biochemistry, plant chemistry having been limited to one chapter. The whole volume has been written from the point of view of a chemist rather than that of a physiologist, the physiology having been kept at a minimum. The tendency throughout has been to discuss the chemistry of substances and processes rather than that of materials. For instance Vitamin A is allotted five pages, the Vitamin B complex seven pages, and the Chemistry of Respiration fifteen pages, while the chemistry of all the various tissues except blood get only six pages in total.

This volume is to be recommended for its free use of structural formulas and equations, and to its liberal supply of graphs and pictures, particularly those relating to the vitamin deficiencies. It is decidedly up-to-date in viewpoint and in the chemistry of the vitamins and hormones, which is changing so fast. The book is written in a very readable manner and set up typographically in a way that is easy to follow.

Many references are given, chiefly to review articles, which after all are the best from the student's viewpoint. The author feels that if references to the original literature are needed, they are amply provided for in the review articles. This book might well be recommended to teachers of organic chemistry as a background for the handling of premedical students. ROBERT D. COGHILL.

Quantitative Analysis; by EUGENE W. KANNING. Pp. xiii, 304; 47 figs. New York, 1938 (Prentice-Halls, Inc., $2.75).—In writing this text the author states that he has sought to develop a logical sequence in the presentation of the theory as well as in the arrangement of the experiments. With this end in view, the sections on theory are set apart from the laboratory directions. Part I includes a treatment of the laws and theories which apply to analysis and general instructions regarding technique and principles of procedures. Part II consists of some of the standard analyses. In both parts the gravimetric precedes the volumetric work. The number of experiments is somewhat smaller than usually given, though sufficient for a short, elementary course. The arrangement of the experiments is excellent. Each experiment is divided into four parts: (a) principles, (b) procedure, (c) notes explaining the various steps, (d) questions and problems. Answers to the problems are given in the appendix, which also includes four place logarithms and some gravimetric factors.

In the theoretical part one may feel that the discussion of oxidation-reduction potentials is not entirely clear, and in the experimental section the reviewer feels that the directions for the determination of magnesium and of barium sulfate could be improved by the use of a Gooch crucible. One rather obvious misprint has slipped through in the directions for dehydrating silica. It is indicated that this may be done by heating at 105-110°, where 1100° would be nearer the proper temperature. JOHN E. VANCE.

Chemical Kinetics; by FARRINGTON DANIELS. The George Fisher Baker Non-Resident Lectureship in Chemistry at Cornell University, Vol. XVII. Pp. viii, 273; 41 figs. Ithaca, New York, 1938 (Cornell University Press, $3.25).—The first three chapters of this book deal with the general principles and theories of chemical kinetics. This is followed by a section in which particular types of reactions are discussed. A chapter on homogeneous gas phase reactions is followed by one on reactions in solution. This section is concluded with a chapter on photochemistry and one on reactions which are activated by electrical methods such as alpha particles, electrons and X-rays. The final section treats three subjects which have been extremely useful in understanding the mechanism of reactions. One chapter each is devoted to infrared spectroscopy, calculation of heats of activation and absolute rates from quantum mechanics and on isotopic tracers.

Throughout the book, Professor Daniels has used illustrative examples from the researches of his own laboratory. These special cases are discussed in complete detail from a critical standpoint. Additional literature references and brief summaries of other reactions are appended to several of the chapters.

The book is very readable and heartily recommended to anyone who wishes an authoritative discussion of modern chemical kinetics

GEORGE M. MURPHY.

GEOLOGY.

Northernmost Labrador Mapped from the Air; by ALEXANDER FORBES. Pp. xix, 234; frontispiece, 177 figures, 6 maps, brochure. New York, 1938 (American Geographical Society, Special Publication No. 22, $4.00).—As has been the case with many expeditions to remote regions, the original incentive in the present instance sprang from "the haunting lure of a wild and almost unknown country." But Doctor Forbes was also alive to the scientific value that might accrue from a trip to northern Labrador. As finally arranged, the expedition offered Mr. O. M. Miller of the American Geographical Society an excellent opportunity to put a new method of aerial mapping to the test, as well as giving Mr. N. E. Odell and Dr. Ernst C. Abbe the chance to study the geology and botany of a little known region.

This volume presents the results of three expeditions, the first and largest one in the summer of 1931, and the two supplementary, purely mapping, expeditions of 1932 and 1935. The last occupied only eleven days, but covered the entire Labrador Coast by air. The two previous expeditions enjoyed, in addition to aircraft, a floating base, the "Ramah" in 1931 and the "Zavorah" in 1932. The first 154 pages of the book are taken up by Forbes' interesting narrative of these expeditions, the next nine pages by some general notes on Labrador, and the remaining 71 pages by the scientific reports. The maps (Scale 1:100,000 with contour interval of 50 meters) are contained under separate cover along with a 25-page brochure by Doctor Forbes, entitled "Navigational Notes on the Labrador Coast."

Hitherto all aerial mapping in regions of considerable relief such as northern Labrador has had to be done by vertical photographs, but the new method designed by Miller permits the use of obliques. Formerly obliques could be used only in relatively flat country such as the major part of the Canadian Shield, where the grid method has been successfully employed by the Canadian Government. Oblique photographs are obviously a great advantage over verticals as regards time and expense in the field, since one oblique can cover many times the area of a vertical. But in the laboratory the making of maps from obliques of mountainous terraine involves great mathematical difficulties. These Miller has overcome to some extent by the invention of the photogoniometer and the single-eyepiece plotting instrument. Because of many interruptions, it took six years to complete the map of northern Labrador between Nachvak Fiord, Cape Chidley, and Ungava Bay. Many photographs remain still untouched and will permit the eventual extension of the survey southward. As a result of his experience and the advances made during these six years, Miller estimates that it would now be possible to map accurately mountainous terraine on a scale of 1: 100,000 "at a rate better than 1000 square kilometers per man per year when the ground control is at a minimum. If a well distributed ground control exists with a density about equal to the number of air stations then this figure should be increased at least 50 per cent."

Odell's report on the geology, most features of which have already appeared elsewhere,[1] emphasizes the geologic structure, its relation to the present landscape, and the glacial geology. The rocks of the region form part of the Canadian Shield. Three mountain groups are present, the Kiglapaits lying just north of Nain and constituting the most southerly group, the Kaumajets near Cape Mugford, and the better-known Torngats, the most northerly and highest group lying just north of Saglek Bay and reaching a maximum height of slightly over 5000 feet. Citing H. C. Cooke,[2] Odell attributes this unusual relief for the Canadian Shield to Pliocene or earlier uplift of a peneplane. An interesting feature of the Torngat area is the fact that the drainage divide lies west of the mountain group through which the principal streams flow. Odell suggests that some of these transverse courses are antecedent, but he gives no good evidence in favor of this possibility.

Odell's views on glaciation have an important botanical bearing and apparently stand in opposition to those of Coleman and Daly, who have pointed out that the jagged character of the higher peaks and their thick, frost-riven cover indicate extensive weathering compared to the lower slopes and that, therefore, the higher points stood above the last continental ice sheet. Odell, on the other hand, basing his views on experience in Spitsbergen and East Greenland, believes that these features, because of their high altitude and favorable location for moisture-laden winds, could have been produced by intense frost action following maximum glaciation. That at least some of the mountains were covered by ice at one time is shown by the fact that Odell discovered traces of glacial polish on a summit having an elevation of about 4700 feet—"that is nearly 3000 feet higher than the elevation others have thought to be the maximum ice level." But he admits that the degree of weathering was consistent with the possibility that the polish could have resulted from a pre-Wisconsin glaciation, although no traces of multiple glaciation were found. Since there is no direct evidence offered that the signs of glaciation observed at high altitudes are contemporaneous with the most recent glaciation, and there is some evidence at least suggestive of the contrary, it would seem risky to accept whole-heartedly the perhaps sympathetic view that nunataks were absent during the maximum glaciation of Wisconsin time.

Abbe in his report entitled "Phytogeographical Observations"[3] points out that only the hardiest members of the flora occur at high elevations, and that it does not seem likely that less hardy relic Cordilleran species now occurring predominantly at lower elevations could have survived a glacial stage even if nunataks were present in Wisconsin time. He therefore suggests the alternative possibility that the relic species owe their presence to migration during a post-glacial climatic optimum, and that their present restricted distribution is due to later refrigeration.

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[1] Odell, N. E.: The Mountains of Northern Labrador, Geogr. Journ. Vol. 82, pp. 193-210 and 310-325, 1933.

[2] Cooke, H. C.: Studies of the Physiography of the Canadian Shield, Trans. Royal Soc. of Canada, Sec. 3, 1929, Sec. 4, pp. 91-120; Vol. 24, Sec. 4, pp. 51-87, 1930; Vol. 25, Sec. 4, pp. 127-180, 1931.

[3] See also Abbe, E. C.: Botanical Results of the Grenfell-Forbes Northern Labrador Expedition, Rhodora, Vol. 38, 1936, pp. 102-161, 1931.

Like most publications of the American Geographical Society, the present volume is very attractively printed, illustrated, and bound.
A. L. WASHBURN.

Late Paleozoic Pelecypods: *Pectinacea*; by NORMAN D. NEWELL. State Geol. Surv. Kansas, Vol. 10, pp. 123, 42 text figs., 20 pls. (in separate binding), 1937 (actual date of issue, July 28, 1938).—In this pace-making book the author treats of the scallop-shells of the Pennsylvanian and Permian formations of North America, with incidental studies of some foreign forms. The species discussed number 83, 30 of them new, and 74 regarded as valid. They are grouped under 28 genera, 8 of which are new and 2 are synonyms. Newell has given much time to the preparation of the specimens, so as to reveal more or less of the hinge characters. There is a valuable glossary of shell terms, and good discussions of the ornamentation, the musculature, the shell structure, and especially of the ligament. Included also are two detailed correlation tables of the formations from which the material has come. Finally, on pages 113-116 is given the generic status of many non-American pectinoids. The author is to be congratulated on his excellent work, and the Geological Survey of Kansas on the good-looking format in which it is issued.
CHARLES SCHUCHERT.

BOTANY.

Cryptogamic Botany. Vol. I. *Algae and Fungi*; by G. M. SMITH. Pp. viii, 545; 299 figs. New York and London, 1938 (The McGraw-Hill Co., $4.00).—Vol. II. *Bryophtes and Pteridophtes*; by G. M. SMITH. Pp. vii, 380; 224 figs. New York and London, 1938 (The McGraw-Hill Co., $3.00).—Cryptogamic Botany, presented in two volumes, is a much needed supplement to the many less advanced texts dealing with the morphology, taxonomy and evolution of the lower plants. With the exception of the recent volume on vascular cryptogams by Arthur J. Eames, this text is the most comprehensive and authoritative since those offered by Strasburger, Sachs and Wettstein. Although designed primarily for more advanced courses covering the entire field of cryptogamic botany, the book is also well adapted for use in more specialized courses dealing individually with the several major groups which constitute the cryptogams. The text is up to date in every respect and includes the recently acquired facts which are particularly abundant in connection with the red and brown algae and the fossil vascular forms. The illustrations are numerous and include habit sketches with figures of both vegetative and reproductive structures with the result that the student is able to gain a clear and complete knowledge of the forms chosen to represent the various groups. The system of classification followed is one to which the author himself has made important contributions. It is modern throughout with phylogenetic relationship clearly indicated. Strong emphasis is placed on progressive development and the author achieves a clear picture of plant evolution within the lower forms as it is understood at the present time. A bibliography follows each section and Cryptogamic Botany serves not only as a complete text but as a work of reference as well.

H. CASTLE.

BIOLOGY.

Fearfully and Wonderfully Made, The Human Organism in the Light of Modern Science; by RENÉE VON EULENBERG-WIENER. Pp. xii, 472; 17 figs. New York, 1938 (The Macmillan Co., $3.50).—The author has been remarkably successful in her attempt to present what science has learned of the human organism and its functions, and to fit man into the universe by explaining in untechnical language the phenomena of life as based on the energy concepts of modern physics. To do this required enlargement upon the treatment of physico-chemical laws and the chemistry of the different functions, and an inquiry into the significance to life phenomena of the peculiar asymmetric structure of biomolecules. By stepping somewhat beyond the evidence of the senses she helps to keep alive the age-old feeling of wonder and awe which has in some degree touched philosophers, physicists, poets and all active intellects.

The detail in description of the various organs is carried considerably beyond the point reached in most popular books. One may cite as an example the author's treatment of the eye where even the metabolism of the lens is clearly explained.

Another part of the book in a very satisfying manner unlocks the intricate mechanisms by which carbohydrates, fats, proteins, water and minerals are used in the body by the digestive and other systems: nor are hormones and vitamins slighted. Other organ systems are well discussed both in their structural and functional aspects. The last chapter considers the human organism as a whole. Seven pages present a part of the extensive bibliography upon which this useful book in part is based. It should prove useful to students as well as laymen. S. C. BALL.

Genetics, An Introduction to the Study of Heredity; by HERBERT EUGENE WALTER. Fourth edition. Pp. xvii, 412; 150 figs. New York, 1938 (The Macmillan Co., $3.00).—This is "a new book under an old title," a beginner's text which, although cast in a different mould, retains the romantic but still solid freshness of its three predecessors. His long experience as a successful teacher and writer has enabled the author to evolve an introduction to genetics which is certain to stimulate every student through one or more of the several approaches that he has provided. These are the observational avenue, the experimental, the statistical, the cytological and the developmental methods of approach, to which are added important chapters on the architecture of the germ plasm, the contributions of sex, the application of genetics to man, human conservation, and problems for practice. Many of the illustrations are new.

Nine useful appendices and a good bibliography amply provide for the student's advance beyond the field embraced by the text. S. C. BALL.

OBITUARY NOTES.

Nature reports the death of M. de la Baume-Pluvinel, member of the section of astronomy of the Paris Academy of Sciences, on July 18, aged seventy-seven.

MR. A. JOHN GREENAWAY, British chemist of distinction, died on August 25, aged eighty-six. Had he not devoted his life to chemistry, he might have been a great artist as was his sister Kate Greenaway. His outstanding and self-sacrificing services to the British Chemical Society will long be remembered.

DR. VOLKMAR KOHLSCHÄTTER, since 1909 professor of inorganic and physical chemistry at the University of Bern, died on September 10 at the age of sixty-five.

DR. ARTHUR STANLEY MACKENZIE, president of Dalhousie University for twenty years, died in Halifax at the age of seventy-three. He had formerly taught physics at Bryn Mawr College, Dalhousie University and Stevens Institute at Hoboken, New Jersey. He wrote one book, "The Law of Gravitation."

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AMERICAN JOURNAL OF SCIENCE

DECEMBER 1938

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A SKULL OF *ORYCTEROPUS PILGRIMI*.

G. EDWARD LEWIS.

ABSTRACT.

An incomplete skull of *Orycteropus pilgrimi* is described. Of the several species of this genus, *O. depéreti* most closely resembles *O. pilgrimi*, but the latter is only 75 per cent as large as the former.

In 1933, Dr. E. H. Colbert (2) described the first known Siwalik ant-bears, which were collected by Dr. Barnum Brown. This material consisted of two cheek teeth in a maxillary fragment (*Orycteropus browni*) and a single M^2 (*Orycteropus pilgrimi*). In 1932, the writer was fortunate enough to find a reasonably complete skull of the second species, and it is described herewith. The American Museum of Natural History, through Dr. Barnum Brown, very kindly supplied a cast of *O. gaudryi,* and the Naturhistorisches Museum of Basel, through Dr. H. Helbing, graciously sent a cast of *O. depéreti* for comparison. The restoration of the Yale specimen was made by Mr. V. R. Short under the writer's supervision, and Mr. Short and the writer collaborated on the photographs.

The Yale specimen of *Orycteropus pilgrimi* Colbert (Yale Peabody Museum No. 13901) is an incomplete skull (Plate, Fig. 1). It was discovered in talus at the foot of a butte one mile southwest of Mathrala, six miles east of Dhok Pathan Rest House, Attock District, Punjab, India; Survey of India Map No. 43 $\frac{C}{8}$, C-2. The matrix of fine sandstone was derived from the cap-rock of the butte, which is made up of rocks of the upper part of the Dhok Pathan formation of middle Pliocene age.

The three right and last two left upper molars are preserved. The matrix bore the natural mould of the right second and third lower molars, which were cast for the restoration. While the skull was incomplete when found, assiduous searching producing no additional fragments, the parts preserved were articulated in the matrix as in the restoration. It is to be

AM. JOUR. SC.—FIFTH SERIES—VOL. XXXVI, No. 216, DECEMBER, 1938.

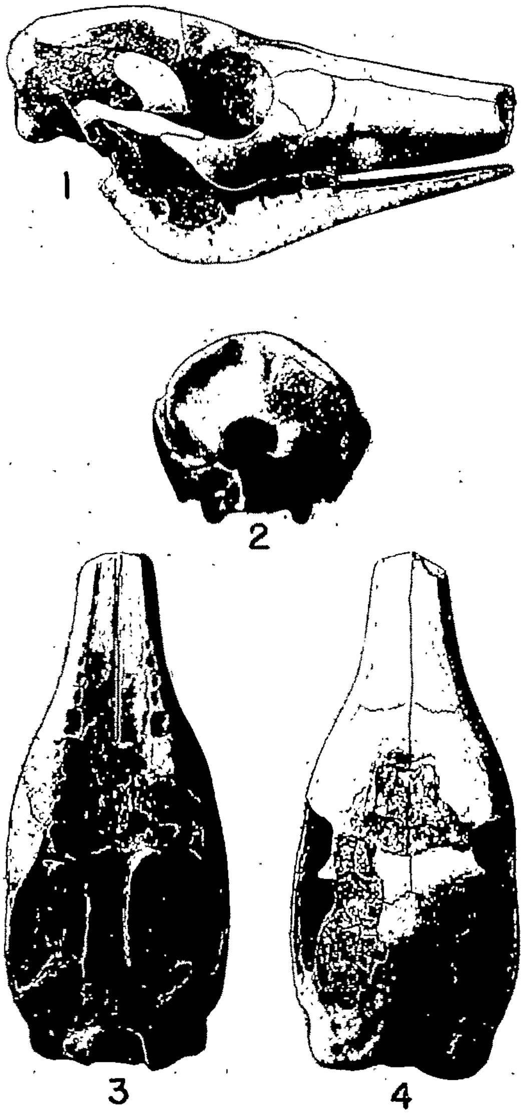

PLATE I.

Restored skull and mandible of *Orycteropus pilgrimi* Colbert, Yale Peabody Museum No. 13901, hypotype; x ½.

Fig. 1. Right side view of skull and mandible.
Fig. 2. Rear view of skull.
Fig. 3. Palatal view of skull.
Fig. 4. Top view of skull.

presumed that the skull and mandible were originally well preserved, due to the presence of the moulds of the lower teeth and the preservation of the right tympanic—a bone which is usually lost in maceration in this genus. Portions of the frontal, parietal, squamosal, occipital, maxillary, palatine, pterygoid, and sphenoid bones of the skull, and the anterior portions of the ascending rami of the mandible are preserved. In general, the preservation is more complete on the right side than on the left (Plate, Figs. 1-4).

The accompanying table of measurements illustrates the fact that *Orycteropus pilgrimi* is intermediate in size between

Table of Measurements in Millimeters.

Species Measurement designation	*Orycteropus pilgrimi*, A.M.N.H. holotype, from figure.	*Orycteropus pilgrimi*, Y.P.M. No. 13901, hypotype.	*Orycteropus browni*, after Colbert.	*Orycteropus depéreti*, after Helbing.	*Orycteropus gaudryi*, from cast.	*Orycteropus capensis*, from Recent specimen.
Width of cranium behind postorbital processes		37		43	36	47
Outside width at postglenoid process		50 est.		67	60	71
Greatest width of occipital surface		47 est.		57	52	65
Length of upper molar series		27.5		33	30	34
Length of M^3		6.7	4.7	10.3	7.5	8.5
Width of M^3		6.6	4.3	7.2	6.2	7.7
Length of M^2	10.2	10	7.7	12.3	12	11.7
Width of M^2	7	6.8	5.3	8.2	7.7	9.9
Length of M^1		9.6		11.8	10.3	12.3
Width of M^1		5.6		7.8	6.6	8.4
Diameter of dental tubules—Average Maximum Minimum	.25 est.	.20 .35 .07	.20 est.		.25 est.	.18

O. browni and *O. depéreti*, and the illustrations show the close morphological approach between *O. pilgrimi* and *O. depéreti* as described by Helbing (3). Study of the Yale specimen indicates that Colbert's criteria for differentiating the plan of the molars of *O. pilgrimi* from that of *O. gaudryi* are valid. In *O. pilgrimi* and *O. depéreti* the molars are less rounded and more squared in plan, and the lingual groove is less pronounced than in *O. gaudryi*. The M^3 of *O. pilgrimi*, while small and peg-like, still has the labial groove which is usually lacking in the living species. Transverse and vertical sections of the tooth tissue were made, and they reveal the same microscopic structure observed in the holotype. The histological peculiarities of the teeth of *O. browni* may be due to the location of the section. The writer found that there is histological variation related to the relative distance between the occlusal surface and the proximal growing surface in the molars of *Orycteropus*, and also to the transverse position between the center and periphery of the tooth. Tangential and radial diameters of the tubules are of little significance unless the position of the tubules is designated, inasmuch as peripheral tubules have greater tangential than radial diameters, medial tubules have greater radial than tangential diameters, and central tubules have subequal radial and tangential diameters. Moreover, there appears to be a definite zonation of tubules as to size, the peripheral, central, and medial tubules being increasingly larger in this order.

Recent *Orycteropus* seems to favor an arid environment. The Ethiopian and Cape species of Africa are separated only by the barrier of the intervening humid region, which apparently was arid in glacial times, allowing for continuous distribution. This stimulates speculation as to the ecology of the extinct species. It is interesting to note that Krynine (4, pp. 435-436) concludes that in late Dhok Pathan time, desert conditions prevailed in the Punjab.

The table of measurements illustrates one evolutionary trend of this genus: while the absolute dimensions of the skull (and the rest of the skeleton) of the Recent species surpass those of the fossil forms, the molars, individually and as a series, have experienced relative reduction.

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THE DISTRIBUTION OF HELIUM AND RADIOACTIVITY IN ROCKS.

NORMAN B. KEEVIL.

I. MINERAL SEPARATES FROM THE QUINCY GRANITE.

ABSTRACT.

As a part of a program initiated in an attempt to discover the source of certain anomalies in some helium age measurements of rocks, experiments were carried out on the separated minerals of the Quincy granite. The "ages" computed from determinations of the helium, radium, and thorium contents were: quartz, 86 ± 5; riebeckite and aegirite, 86 ± 5; and feldspar (chiefly microperthite), 49 ± 3 M.y. The weighted age calculated from these data and the mineral composition was in agreement with the age determined from the granite itself, 62 M.y. While a similar "low age" for a Precambrian Labradorite from the Adirondack Mountains (101 ± 10 M.y.) suggests that leakage from feldspars might be prevalent, it is considered more likely on the basis of previous diffusion calculations, examinations of the thin sections of all specimens used in this work, and the high degree of alteration of the Quincy feldspar, that the loss is due in this case to excessive crystal imperfections.

It is considered significant that although the concentrations of radioactivity and helium in the riebeckite and aegirite were five times as great as in the other minerals, a "high age" was obtained, showing no tendency for helium to diffuse towards a uniform concentration during geologic time. Because no such differences were observed in nine consistent experiments on the rock itself, it is suggested that this distribution between the mineral constituents is characteristic of the Quincy granite.

Further experiments are planned to show whether helium ages may be low due to feldspar leakage, and whether the most reliable results on rocks are to be obtained only from quartz and certain ferromagnesian minerals.

INTRODUCTION.

An added interest in the nature of the distribution of traces of helium and the forces by which they are held within crystals has arisen from some recent developments in the field of helium age work. In the course of a long series of experiments on the determination of the geologic age of igneous rocks by the helium method, certain anomalies were discovered. The first results obtained were markedly lower than previously published ages of contemporaneous rocks, and differences were obtained between the helium ages of granites and basalts, and between those of granites and pegmatites from the same geological horizon. The discrepancy with previous ages was found to be due to more or less systematic errors in previous experiments, and the difficulties involved have been discovered and partially eliminated.[1]

The best proof of the general validity of the new results is the concordance between the two entirely independent methods of determining the helium age.[2] Such agreement has strengthened the concepts upon which the methods are based, and removed certain doubts as to the reproductibility and significance of the results, but there are still some apparent discrepancies that remain to be explained. The work reported in this paper represents only a part of a comprehensive coöperative program both of development and of application of radioactive methods to geological problems.

While there are far from sufficient age results for granitic type rocks to construct a complete time scale, there are enough to indicate the possibility of building up such a scale for use in geochronological studies. The span in age of those rocks already analysed[3] is from 40 million years in the late Paleozoic to 1000 M. y. in the Precambrian. Nevertheless, the ages seem to be lower than those found for basic trap rocks of apparently corresponding geologic ages. In the experiments with pegmatites, the ages computed from the helium and minute radioactive content did not agree with those for the associated granites, and in this case the difference did not appear to be quite so systematic. All of these results suggested that more fundamental experiments were necessary, and that an inquiry should be made into the nature of the distribution of helium and radioactive materials throughout the rock.

A full discussion of the theoretical aspects of the problem of helium retention has been given in a previous paper.[4] It was concluded that no loss of helium could occur through the atomic structure of common rock minerals, but a small quantity could escape through crystal imperfections and the interstices between crystals. That much, if not all, of the helium is held in the rock, closely associated with the parent radioactive atoms, is indicated by the magnitude and concordance of the age results. There are also a number of other experiments indicating its strong retention in rocks. Grinding of specimens to varying granularities has not yielded any signficant differences in the helium content, the same values being obtained for the finely powdered rocks as for coarse chips. This is not to be confused with those showing loss of helium from grinding of radioactive minerals which might contain many million times more helium. As an example of an experiment on an ordinary rock, Urry found a Keweenawan basalt of unusually high helium content to give the same value, 39×10^{-5} cc./g., whether the specimen was in one or several pieces, or finely powdered. In fact, the helium is held so firmly within rocks that none is liberated until quite high temperatures are reached. In metals,[5] heating at 1000° C. for several hours removed only the helium adsorbed at the surface, while in rocks,[6] the helium is not expelled appreciably until temperatures of 700-800° C. Diffusion experiments have shown that while helium may pass through the channels in glasses and between crystals, individual crystals are impermeable to it even at high temperatures.[4]

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[1] Evans, Goodman, Keevil, Lane, and Urry: Phys. Rev., in press.
[2] Keevil and Goodman: J. Geol., in preparation.
[3] Keevil: Bull. G.S.A., in preparation.
[4] Keevil: Proc. Am. Acad. of Arts & Sci., in press.

Just how the radioactive atoms are distributed through rocks, in what form they exist, and with what minerals they are associated, is an important mineralogical problem, and of direct interest to age work—especially if there is a difference in the retentive power of different minerals for helium as the results reported below would suggest. Early data concerning the distribution of radium in igneous rocks have been summarized by Evans and Williams,[7] and a series of recent results on radium and thorium is presented in another paper.[8] Merely from a consideration of the chemistry of mineral formation, one might expect the radioactive atoms to occur in certain mineral forms, and to be associated with a certain class of minerals in rocks. The experimental evidence as to the location in rocks varies considerably, but the activity does seem to be concentrated in certain minerals, usually in some of the very minor accessories. It seems unlikely that there is any concentration at the surfaces as has been suggested. The scattering of inclusions through the body of major rock minerals certainly does not suggest any such localization. Because the visible inclusions and pleochroic halos account for only a small fraction of the measured radioactivity of rocks, or of a commonly active mineral such as biotite, it would appear that there is also little localization throughout the mineral structures and that many atoms are distributed at random throughout the crystal network.

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[5] Paneth and Urry: Z. Phys. Chem. A 152, p. 127, 1931.

[6] Evans and Goodman: in preparation.
Holmes, and Paneth: Proc. Roy. Soc. London, A, Vol. 154, pp. 385-413, 1936.

[7] Evans and Williams: This Journal, 29, 441-452, 1935.

[8] Keevil: Econ. Geol., in press.

The anomalies in the age results mentioned above suggested that experiments should be performed on the separate mineral constituents of a rock. Such experiments should prove valuable in studying the distributions of these minor constituents throughout the rock, in ascertaining whether there is any tendency for diffusion of helium towards a uniform concentration, and in testing the accuracy of the helium age. Since both age experiments and the theoretical treatment[4] have indicated that the helium is retained within the crystal close to the parent radioactive atoms, even although the latter are probably at quite different concentrations in different minerals, it should be possible to determine the age of individual minerals in a rock. As a matter of fact, such an assumption is implied in the sampling procedure followed by Urry, and which has been followed for most of this work so as to retain comparable procedures. The rock is broken up in steel mortars to about the granularity of coarse table salt, and the powdered material and the coarser grains separated by a kind of panning procedure using clean paper sheets. Such a method does not guarantee an average sample; it is more likely that sometimes the softer and lighter constituents and some feldspars might be concentrated in the fine powder, while heavier minerals such as the ferromagnesians might be present in excess in the coarse heavier portion. However, control experiments have indicated that such a separation does not take place to any great extent, or at least does not ordinarily affect the results. In a few cases, there were variations in the radium contents of the portions of different grain sizes, but when all of the determinations are carried out on one sample, such sorting has not been considered important.

EXPERIMENTAL.

The rock selected for this problem was that which had previously been studied in greatest detail.[3] A large number of determinations on the Quincy granite had shown that the distribution of radioactivity and helium was fairly uniform over a wide sampling range, so that this rock seemed quite suited for this purpose.

The minerals in the Quincy granite were segregated by means of nickel forceps after breaking up the rock to the point where most of the minerals were separated. This was readily done in a few hours with such a coarse-grained granite. The three main constituents, quartz, feldspar, and ferromagnesians (riebeckite and aegirite), were separated, and while not pure samples, were probably better than 95 per cent, which is quite satisfactory for the present purpose. The feldspar crystals are not pure feldspar in the first place, since they have a number of inclusions of ferromagnesians and have suffered some deuteric alteration. To guard against any possible error due to helium escape, helium analyses on the rock itself and on the feldspar and ferromagnesians were made within twenty-four hours after sampling, while the quartz was done the next day. The results are given in Table I.

TABLE I.

Age Data on Quincy Granite Minerals.

No.	Sample	He × 10^5 cc./g.	Ra × 10^{13} g./g.	U × 10^6 g./g.	Th × 10^6 g./g.	Th/U	Age, M. y.
QFM	Ferromagnesians	11.4 ± 0.1	17.8 ± 0.54	5.05	25.0 ± 0.38	5.0	86 ± 5
QQ	Quartz	2.60 ± 0.06	6.1 ± 0.2	1.73	3.40 ± 0.27	2.0	86 ± 5
QF	Feldspar	1.54 ± 0.02	4.15 ± 0.21	1.18	6.19 ± 0.20	5.2	49 ± 3
Ave.	Weighted average of minerals	2.75	6.0	1.7	7.0	4.1	68 ± 4
Q5	Rock itself	4.33 ± 0.04	9.8 ± 0.32	2.78	12.4 ± 0.47	4.5	63 ± 3
Qave.	Quincy granite (average values)	3.9	10.6	3.0	9.3	3.1	62 ± 2

While these results represent only a single series of experiments on a single rock, some confidence can be placed in them because the observed distribution of radioactivity and ages is internally checked by the agreement between the ages obtained for several measurements of the complete granite and the weighted age computed from the results on the minerals combined with the average mineral composition of the rock. The results are presented now because they represent a new attack of the age method, and promise to yield information of fundamental importance in this work.

It will be noted that most of the radium and thorium are associated with the riebeckite and aegirite, and more significant, that the helium is distributed similarly. If the diffusion were an important factor, one would expect the helium to have diffused to a uniform concentration throughout the rock during the millions of years since it first commenced to accumulate. If there had been any diffusion at all, there should have been some escape from the ferromagnesians because of the relatively large excess of helium in these minerals. The age computed from the experimental observations would then be low. Actually, the highest age was obtained for this mineral. This is convincing evidence for the retention of helium in these minerals and against its escape or diffusion to a uniform concentration. It is probable that the observed distribution between the minerals is a characteristic of the Quincy granite, for the helium, radium, and thorium contents of the rock are fairly uniform over a considerable distance, and in no case were concentrations of helium observed which approached those reported above for the ferromagnesians.

Specimens of the Quincy granite were taken from a range of from twelve to over six hundred feet in neighboring quarries separated by about a hundred yards, and others were sampled from a quarry three miles distant. The values found in a series of determinations were as follows:

Helium $\times 10^5$ *cc./g.*
3.0, 3.9, 3.3, 4.8, 4.1, 2.75, 3.54, 4.33, 5.31, and 4.18.
Radium $\times 10^{13}$ *g./g.*
10.35, 7.75, 10.9, 12.85, 12.2, 9.50, 9.8, and 12.5.
Thorium $\times 10^6$ *g./g.*
5.9, 10.6, 7.8, 10.2, 9.0, 7.0, 12.4, and 11.7.

The low age obtained for feldspars is difficult to explain, and is being checked by further work on mineral separates from rocks. It may be interesting, however, to discuss some of the possibilities. The possibility of diffusion of helium into other minerals to give an uneven age distribution in the rock has been discounted in previous considerations.[4] The diffusion of helium to the largest reservoir is likewise improbable. It is generally accepted that the atoms in a crystal behave more or less as symmetrical spheres of constant size for a given environment, and that some sort of free space exists between these even in a close-packed network. The free space considerations in the previous paper have shown that feldspar has the most open structure of common rock minerals, so that if diffusion took place to such a "reservoir," feldspar should have an excess of helium, whereas the opposite was found. Another possible explanation is that of uneven sampling of helium and the radioactive constituents. In one case some radioactive atoms may have been sampled, say at crystal surfaces, while some of the helium emitted from them may have been rejected in the adjoining piece, and in another case the opposite might be true. Finally, it is possible that, due to some peculiarity of these feldspar crystals, helium may have escaped. Some additional evidence that this may be the case is the result found by Urry and the author on a Labrodorite from Chapel Pond, New York. The values obtained were:

$\mathrm{He} = 1.22 \times 10^{-5}$ cc./g. $\qquad \mathrm{Th} = 1.16 \times 10^{-6}$ g./g.
$\mathrm{Ra} = 0.258 \times 10^{-12}$ g./g. $\qquad \mathrm{Th/U} = 1.6$
$\mathrm{U} = 7.3 \times 10^{-7}$ g./g. $\qquad \mathrm{Age} = 101 \pm 10$ M.y.

This is a considerably lower age than was expected, as the rock is thought to be Precambrian. Too much importance should not be attached to this "low" result as a property of feldspars, however, since there is evidence that the helium had escaped through metamorphism in this case, and the probable error of the age determined geologically is large.

If the feldspar crystals were perfect, no loss of helium could occur, and even with a normal amount of crystal imperfection the permeability would be low, as shown in the previous paper.[4] It may be, though, that there is an excessive degree of imperfection in the Quincy granite feldspar and that this accounts for the low age value. Certainly, one would expect the feldspars to be the extreme in this respect, because of the frequency of various sorts of intergrowths and alterations. The latter are generally of the deuteric type, but might leave the crystal susceptible to the escape of gases. Some types of perthites also may contribute to this effect, especially those formed by replacement processes, and those where the difference in size of replacing ions is very great. The resulting distortion might be significant, especially if the crystallization was rapid and the system thus not always kept at equilibrium. The feldspars in the Quincy granite have undergone a number of deep-seated alteration processes, which may leave the crystals partially permeable to helium. Thin sections were made of all the granite specimens that were used for this work, and the petrography had been done previously by Warren. The main

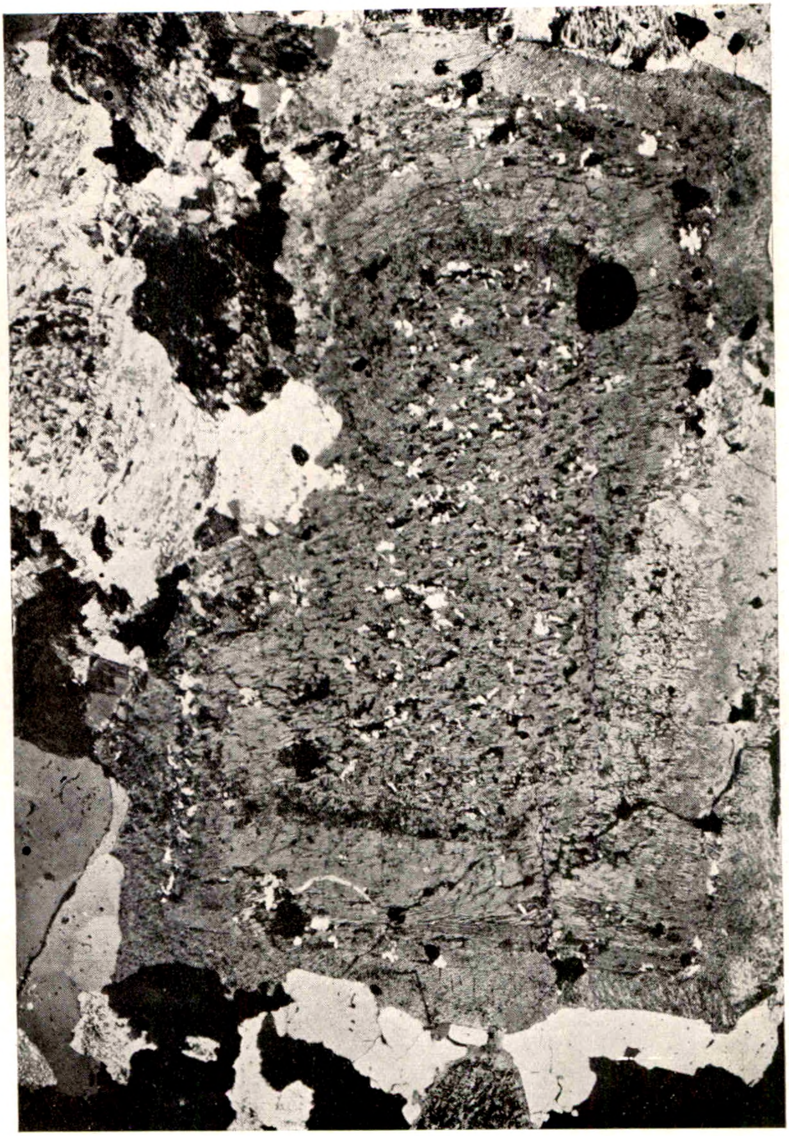

Fig. 1a.

A. Photomicrographs of feldspar in thin sections of the Quincy granite, showing the large number of inclusions and excessive crystal alteration, some of which commenced along zonal boundaries. Crossed nicols. x 18.

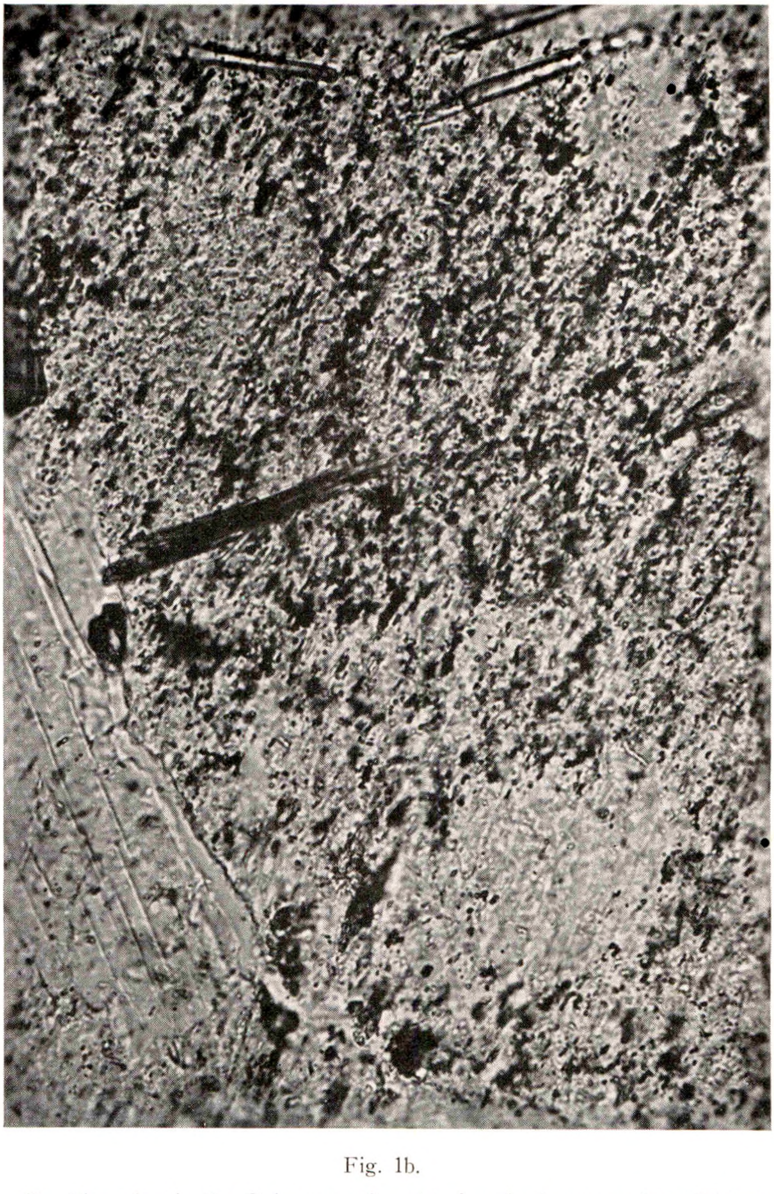

Fig. 1b.

B. Alteration in the Quincy granite, showing the large number of intrusions of opaque material. Plain light. x 600.

constituents are: feldspar (chiefly microperthite), 60 per cent; quartz, 30 per cent; riebeckite with aegirite, about ten per cent. The microperthite consists of about equal proportions of orthoclase and albite and there is an excess of albite (over the original high temperature mixed crystal) which has formed along crystal boundaries and interstices and further attacked the microperthite during late magmatic stages. There are also evidences of later reactions than this; especially in the associated porphyries. Warren observed that grains of albite and perthite crystals are often included in the original microperthite, sometimes a mosaic of feldspar grains replacing a large part of the original feldspar crystal. Albite encroaches on the margins, and in some cases cuts across the perthitic strips. It is possible that some much later mineralizing albitic solutions selectively attacked the feldspars, thus providing a lower helium age. It is probably more orthodox to assume that the deuteric reactions occurred as a late magmatic stage, leaving the crystals more or less imperfect. Although the microliths of the ferromagnesians are distributed at random throughout the feldspar crystals, there are other dark particles and cavities, only partly filled with brown and black material, that are concentrated along cleavage cracks which are now healed with fresh albitic material. This means that the material was injected through the cleavage directions after the crystals had been cleaved by strain. The number of these inclusions varies considerably, but they predominate in the darker varieties of the Quincy granite; they are seldom greater than 3/1000 mm. in size. The presence of so many probably affects the density, and must make chemical alteration easy. There are a few scattered spots of limonite, even in the deepest Quincy quarries, which indicates some alteration, possibly from weathering processes. Otherwise the granite is quite fresh and uniform.

The first consideration of the problem suggested that owing to the extent of perthitic and intergrowth structures formed by exsolution and replacement, due in part to the distortion of the crystal in substitution of different sized ions (sodium and potassium), feldspars might always exhibit enough imperfection to cause helium leakage. However, a survey of some thirty thin sections of rocks which had been used for age determinations failed to show any systematic relation of possible age discrepancies to the type, quantity, or degree of alteration of the feldspars. Furthermore, some experiments in progress on minerals from the pegmatite at Fitchburg, Mass., yielded some anomalous results which showed that the feldspar age may be off in the opposite direction. This latter case is complicated by the presence of radioactive minerals and possible contaminations of helium, radium, or thorium.

From a consideration of theoretical diffusion calculations and of other age results, it is not thought likely that helium escapes from all feldspars to the apparent extent found above. Nevertheless, obtaining such a result suggests the possibility that helium leakage may be prevalent in this class of minerals, and since they are the predominating rock-forming mineral in the earth's crust, this would lead to low "ages" of rocks when determined by the helium method. This would not invalidate any work on rocks unless this factor were quite variable. This does not appear to be the case, because the distribution of the helium ages of rocks from the present to one and a half billion years ago is concordant with the geological succession. The fact that the individual ages fit closely with their positions in the existing geological time scale indicates their value for geochronological purposes. Here the sequence and relative age are important, and these can be obtained from the helium age index of rocks.

If it should be found that many feldspars do permit the escape of helium, absolute helium age determinations will be obtained only from certain minerals and not from the rock as a whole. If such is the case, it may prove advisable to direct future work to certain unaltered minerals from rocks, such as quartz, pyroxenes, and amphiboles. Further research on this important question is in progress.

ACKNOWLEDGMENTS.

The writer wishes to acknowledge his indebtedness to the Royal Society of Canada for a Fellowship in Geological Sciences, and to the Geological Society of America for support of a part of this research.

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SIGNIFICANCE OF PLEISTOCENE DELTAS IN THE MINISINK VALLEY.

STAFFORD C. HAPP.

ABSTRACT.

The Minisink Valley is a part of the Delaware River drainage basin in southeastern New York, northwestern New Jersey, and northeastern Pennsylvania, lying just southeast of the margin of the Appalachian Plateau. It is about 65 miles long, from northeast to southwest, and averages about three miles in width. It is within the area of Pleistocene continental glaciation and aqueoglacial deposits cover most of the valley bottom. The texture and structure of these deposits suggest rapid accumulation by torrential streams. Kame terraces are the most common form of these glacial deposits, but there are also isolated kame hillocks, at least one esker, and several pro-glacial deltas. The irregularly variable elevations of the delta topset-foreset contacts suggest deposition in a number of disconnected lakes between the valley sides and ice occupying the valley floor. The ice may have been a residual tongue persisting after most of the adjoining higher lands had been uncovered by melting, and it may have been at least partly stagnant. There is, however, at least one "recessional" moraine in the valley, indicating that a live ice front existed for some time behind the recognized southern limit of the last Pleistocene glacial stage. Post-glacial modification of the surface has been slight, except for the development of flood plains along the present streams.

INTRODUCTION.

Minisink Valley is a local name for a part of the Delaware River drainage basin, lying between the Appalachian Plateau front and the continuous homoclinal ridge, variously known as Shawangunk Mountain, Kittatinny Mountain and Blue Mountain, in southeastern New York, northwestern New Jersey and northeastern Pennsylvania. It is about 65 miles long, from northeast to southwest, and averages about three miles wide.

The name "Minisink Valley" does not appear on the U. S. Geological Survey topographical maps, but it is defined in Lippincott's Gazetteer[1] as "an Indian name for a portion of the valley of the upper Delaware River, beginning a short distance above Delaware Water Gap, Pa." The word "Minisink" means "the land from which the water is gone," and according to tra-

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[1] "A Complete Pronouncing Gazetteer or Geographical Dictionary of the World," edited by Angelo Heilprin and Louis Heilprin, J. B. Lippincott Company, Philadelphia and London, 1931.

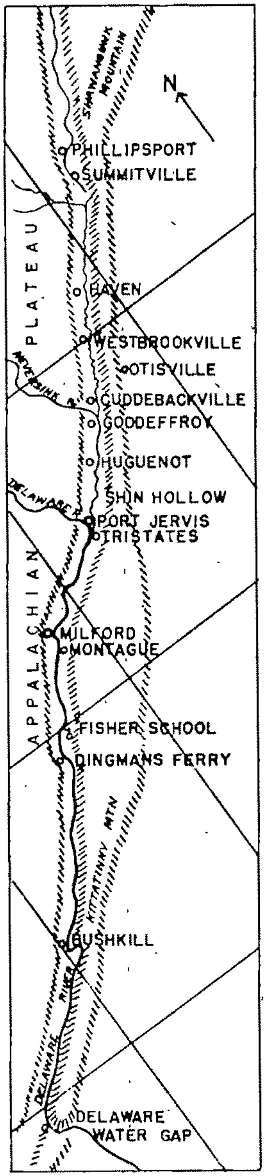

Fig. 1. Index map of the Minisink Valley, showing location of the places mentioned in the text. The scale is approximately thirteen miles to the inch.

dition the aboriginal inhabitants, the Minsies, first occupied the Valley after a great lake had been drained off by the breaking of a barrier which held it in. There is a widespread popular belief that the breaking of this barrier was the origin of the Delaware Water Gap, although geologists have long recognized that the Water Gap had no such catastrophic origin but is a normal feature of the landscape due to the quartzitic rock of Kittatinny Mountain, which is more resistant to erosion than the shales and limestones which outcrop on either side. There are, however, geomorphic records of lacustrine conditions in the Valley during the closing stage of the Pleistocene glaciation, and there may be basis for speculation as to whether the Indian name indicates a traditional record of such conditions, which it seems could hardly have existed less than some ten thousand years ago.

SEDIMENTARY DEPOSITS OF MINISINK VALLEY.

Fluvial erosion, effectively controlled by variations in rock resistance and structural patterns, has determined the larger geomorphic features of the Minisink Valley region. There is no clear evidence of more than superficial glacial erosion, although the Minisink Valley may have been deepened and rounded by glacial scouring. The present surface of the valley bottom is, however, mostly of constructional origin. The streams are poorly graded, with frequent rapids over boulder beds or rock outcrops, but they are everywhere bordered by well developed flood plains. In most places the present flood plains are flanked, on one or both sides, by stream terraces representing former, higher flood plains. There are also numerous higher terraces composed of fluvial or lacustrine deposits that were formed in close proximity to the glacial ice, or by waters derived directly from the glacial melting. These aqueoglacial deposits are marked by typically diverse content, and by structures and texture suggestive of rapid accumulation by torrential streams. In many places the surfaces are hummocky, due to accumulation around or over ice which later melted and allowed the adjoining or overlying sediments to settle into hummocky forms. Kame terraces along the valley sides are the most common form of these aqueoglacial deposits, but isolated kame hillocks are not rare, and there are several proglacial delta terraces and at least one esker. The proglacial delta terraces are particularly important as guides to the interpretation of the origin and history of the Valley deposits, and they form the principal subject of this paper.

DESCRIPTION OF THE DELTA TERRACES.

No trace has been found of wave-marked shorelines associated with the delta terraces, perhaps because such features have been obliterated by stream action, slope wash, and mass movements. There may never have been a strongly marked shoreline, because of the short time that water stood at any one level; the short ice free season during which wave action would have been possible, and the short fetch of open water in which waves could have been generated.

The only one of the terraces in which the delta structure is well exposed is on the northwest side of the valley at Cuddebackville. Here a gravel pit about 300 feet square exposes 28 feet of poorly stratified but approximately horizontally bedded, poorly sorted topset gravel, with cobbles up to three inches in diameter mixed with sand and silt. These lie with sharp and nearly horizontal contact on clean, well sorted foreset sands, which dip 20 degrees southeastward. The terrace, which may be only a remnant of the former extent of the delta, is rudely triangular in plan, with its eastern and southern sides sloping down steeply to the valley bottom. The northwestern side is separated by an elongate depression from terraces at the same elevation which extend in either direction along the valley side, one northeastward along the northwest side of the main valley, the other westward, with gradually rising surface, into and up the northern side of the Neversink valley, which here emerges from the plateau. The proximity of the Neversink River, with the terrace extending along it from near the delta and at the elevation of the delta surface, and another similar terrace at approximately the same elevation along the northwest side of the main valley just south of the Neversink, suggest that this stream furnished at least part of the material composing the delta, and that the same stream has probably removed part of the delta while cutting down to its present position.

The origin of the depression separating the delta from the other terraces on the northwest is not clear. It may be an elongate kettle formed by the melting of ice which had been buried during the building of the delta, or it may be a channel cut by some stream flowing across the delta after its formation, either emerging from the Neversink valley, or flowing outward from an ice front which may have been in contact with the northeastern margin of the delta. Several large, closed kettle holes occur in the delta terrace, indicating the presence of glacial ice while the delta was being built.

Five other terraces in the Minisink Valley are classified as deltas, each being similar to the Cuddebackville terrace in surface appearance, having notably smooth surfaces with more uniform slope than the common kame terraces, and in each of which partial exposures show an approximately horizontal contact between what appear to be coarse topset beds and underlying finer foresets. There are also two deposits showing delta structure, but without the typical delta form, and one terrace which resembles the deltas in surface appearance but in which it has not been possible to establish with assurance that delta structure is present.

On the northwest side of the valley at Westbrookville, four miles northeast of Cuddebackville, a delta terrace has almost exactly the same relation to the Pine Kill, a tributary entering the valley from the northwest, as the Cuddebackville delta terrace bears to the Neversink River. The topset-foreset contact is exposed at an elevation of 576 feet near the northeastern margin of the terrace, where eight feet of coarse topset gravel overlies coarse sand dipping ten degrees southwestward, and apparently at least 50 feet thick although not completely exposed.

The most northeasterly of the deltas is at Summitville, a mile northeast of the present divide between Delaware and Hudson drainage and nine miles northeast of the Westbrookville terrace, the nearest of the other delta remnants. There is a high terrace on the east side of the valley, with a smooth surface except where pitted by kettle holes and where crossed by a small valley which was once partly a kettle depression. The terrace surface rises gently and smoothly northeastward, at a slope of about ten feet per mile, to a pass between the backslope of Shawangunk Mountain and an elongate hill of drift in the valley which Cook[2] interpreted as a crevasse filling. This situation suggests that the terrace was built by a stream emerging, through the narrow pass east of the drift hill, from ice resting against the northern part of the hill. There is now no indication of any other stream which could have brought into place the material composing the terrace. Figure 2 illustrates these relations.

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[2] Cook, John H.: "The Disappearance of the Last Glacial Ice Sheet from Eastern New York," N. Y. State Mus. Bull. 251, pp. 158-176, 1924.

The present scarp at the terrace front appears to have been undercut and shaped by drainage presumably forced across the nearby divide between Delaware and Hudson drainage by an ice barrier lying to the north. A small terrace on the opposite side of the valley, with a smooth top at about the same elevation, suggests that the valley may possibly have been filled entirely across to this level. This would be to an elevation of 600 feet, or about 50 feet above the present valley bottom.

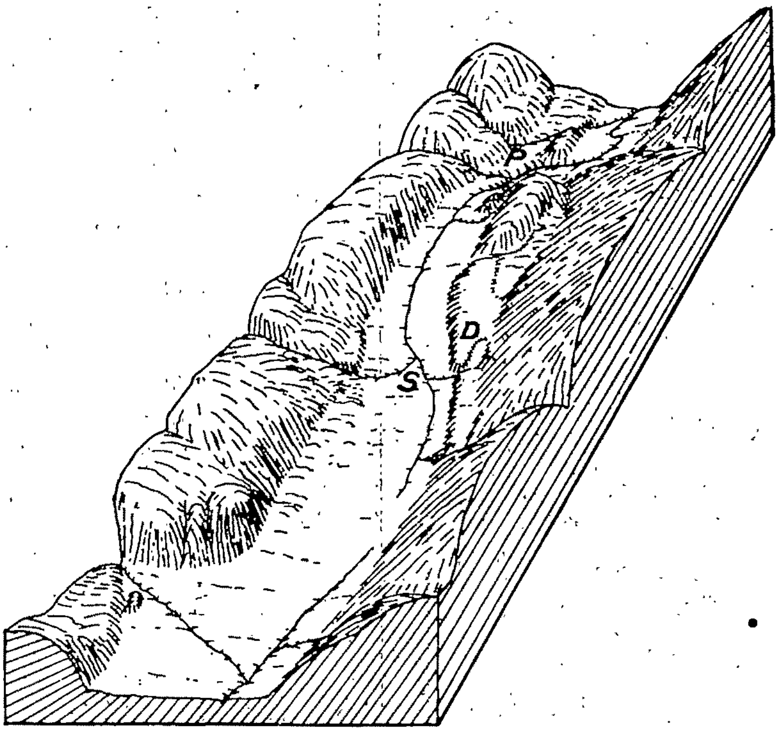

Fig. 2. Part of the Minisink Valley in the vicinity of Summitville (S) and Phillipsport (P), showing the Summitville delta terrace (D). The divide between Hudson and Delaware drainage is a short distance southwest of Summitville, within the area shown.

This interpretation of the origin of the terrace is partly similar to that proposed by Rich[3] except that he described the terrace on the east side of the valley as a remnant of an outwash plain, rather than a delta, built in front of a late Wisconsin glacial margin. However, exposures in the southern part of the terrace show coarse bouldery gravel, with indistinct structure, lying with nearly-horizontal contact over gravelly sand which dips about ten degrees southwestward. Although the exposures are small, these relations are considered indicative

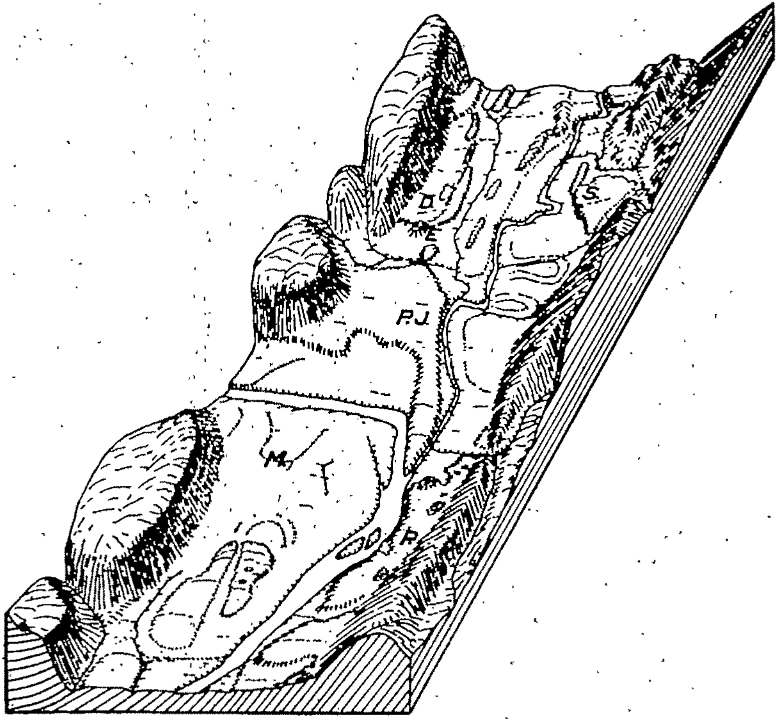

Fig. 3. Part of the Minisink Valley in the vicinity of Port Jervis, showing terraces near Matamoras (M), a terrace which Salisbury suggested might be a remnant of an outwash plain (P), the Port Jervis delta terrace (P. J.), a delta at the southern end of the Martins Lake esker (E), another delta west of this esker (D), and the Shin Hollow delta terrace (S). The Delaware River enters the valley from the west at Port Jervis, and is joined by the Neversink which flows southwestward through the valley to its confluence with the Delaware.

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[3] Rich, John L.: "Glacial Geology of the Catskills." N. Y. State Museum Bulletin 299, p. 66, 1935.

of delta origin. In one place the topset-foreset contact is apparently at 562 feet, but not clearly exposed. In another place what appear to be foreset beds extend up at least to 567 feet and are overlain by topset gravel, but the exact contact could not be exposed because of objections to digging at this point. Five hundred and sixty-seven feet is, however, used in the further discussion in this paper as the nearest approximation to the true water level elevation.

Another delta terrace is on the southeast side of the valley near where the Shin Hollow brook empties into the Neversink about six miles southwest of Cuddebackville, where the topset-foreset contact is at an elevation of 489 feet in the scarp at the outer, western edge of the terrace. This delta is shown in Fig. 3.

The largest delta terrace is occupied by part of the city of Port Jervis, extending out from the northwest side of the valley immediately northeast of the point where the Delaware River enters the Minisink Valley, eight miles southwest of Cuddebackville. The location with respect to the Delaware is similar to that of the Cuddebackville delta to the Neversink River, and the Westbrookville delta to the Pine Kill. There is no exposure showing topset and foreset beds over any considerable area, but numerous shallow cuts show poorly sorted, coarse, bouldery beds at and close below the surface, and underlying fine sands can be seen where the outer margin of the terrace has been undercut by the Neversink River. In a small pit at the northeastern edge of the terrace what appears to be the topset-foreset contact is at an elevation of 452 feet, with the foreset beds dipping five to ten degrees northeastward. The distinction between topsets and foresets is not as clear as might be wished, but the elevation given is believed to be at least close to the maximum elevation at which foresets occur and, for the present purpose, it will lead to no important error if it shall later be found that the contact marking the water level on this delta is actually lower than the figure here adopted.

Less than half a mile north of the Port Jervis delta terrace there is a pit opened in the southern end of an esker, which may be called the Martins Lake esker, where about six feet of coarse, poorly sorted and poorly stratified gravel overlies finer, sandy gravel dipping five degrees southward and grading downward into clean sand. Although the distinction here is not always sharp, this looks like delta structure with the topset-foreset contact at approximately 472 feet. Northward from this point the western side of the esker is a gentle slope which merges into a lower terrace surface between the esker and the nearby valley wall. About half a mile north of the southern end of the esker there is a large, elongate kettle separating the esker from this lower terrace surface. An excavation shows delta structure in the terrace just west of the kettle hole, where poorly sorted, coarse, topset gravel, three feet thick, overlies 20 feet of sand and sandy gravel dipping five to ten degrees southwestward. The topset-foreset contact here is at 453 feet, essentially the same as in the Port Jervis delta, but 20 feet lower than in the delta at the end of the esker, which is intermediate in position, and 35 feet lower than in the Shin Hollow delta which is almost directly across the valley.

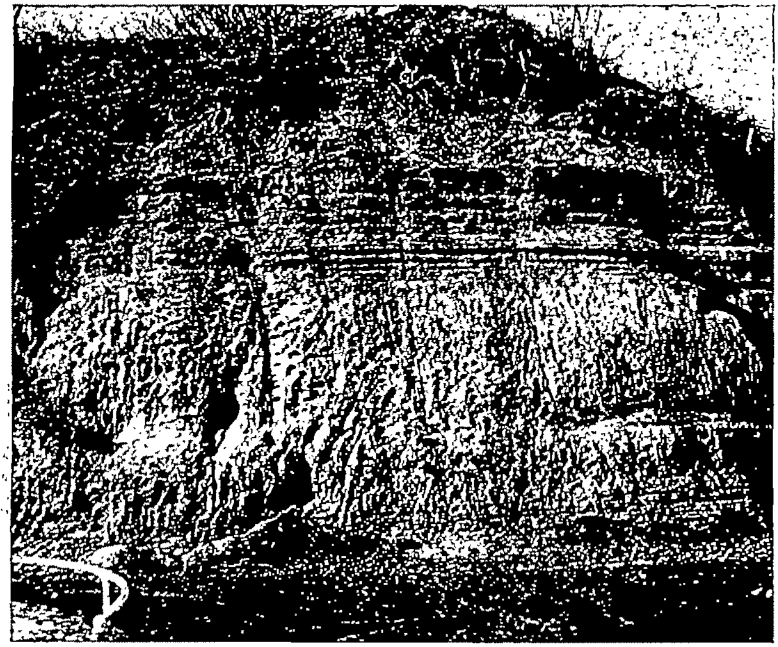

Fig. 4. Exposure of homogeneous silt, suggestive of bottomset beds, in lower part of scarp at outer edge of the Milford delta terrace. The nearly vertical bank is honeycombed with birds nests. Gravelly foreset sand is poorly exposed in the upper part of the bank, and bouldery topset beds farther up the slope, beyond the view.

The most southwesterly of the undoubted delta terraces is at Milford, seven miles southwest of Port Jervis, where most of the village is built on it. This terrace occupies a re-entrant in the northwestern wall of the valley, through which two tributary streams enter the main valley. In a bluff where the Delaware has undercut the outer margin of the terrace there is an exposure showing 28 feet of silt, suggestive of bottomset beds, overlain by 22 feet of sandy gravel dipping ten degrees southeastward and finally three feet, or more, of coarser, bouldery topset gravel. The topset-foreset contact is at 453 feet, practically the same as at Port Jervis and in the terrace west of the Martins Lake esker.

From Milford southwestward to the Delaware Water Gap, where the Delaware leaves the Minisink Valley, there are terraces near the mouth of every important tributary, which may represent deltas, but in none of these has it been possible to find proof of delta structure. One which most strongly suggests a delta is at Bushkill, where the Delaware turns abruptly eastward across the minor hogback ridge. The main valley, opened on Onondaga limestone and overlying shales, continues on southwestward, being drained for some distance by a retrograde stream flowing northeastward to the Delaware. Here a terrace on the eastern side of the main valley, built against the hogback ridge, has a smooth surface sloping gently down northeastward toward the Delaware, and partial exposures show coarse, poorly sorted, bouldery gravel, suggestive of topset beds, lying above fine sand at an elevation of 398 feet at the only place where it has been possible to expose the contact. The sand is at least eight feet thick, and the gravel seems to extend upward to the terrace top at 410 feet. But it has not been possible to determine with certainty that the sand represents foreset beds, and hence this is not definitely classified as a delta.

Still farther downstream there are terraces, which may be deltas, near the confluences of Marshall Creek, Broadhead Creek and Cherry Creek with the Delaware, all within a few miles of the Delaware Water Gap, but delta structure has not been proven in any of these. There is also a terrace on the west side of the valley at Huguenot, four miles northeast of Port Jervis, which may be a delta but which has not been definitely so classified for lack of proof of delta structure.

SIGNIFICANCE OF DELTA WATER LEVELS.

The most important feature of a delta, for purposes of interpretation, is the contact between topset and foreset beds, which in a small lake approximately marks the surface level of the body of water into which the delta was built. This contact can be accurately located and seen to be approximately horizontal in the Cuddebackville delta over an area of more than an acre, and in the delta at the end of the Martins Lake esker it is possible to observe the contact virtually across the entire delta, a distance of two hundred feet. In all of the other deltas apparent topset beds, similar to those of the Cuddebackville delta in texture and structure, can be clearly seen to overlie more cleanly sorted and more steeply dipping foreset beds. In every case the contact has been exposed in at least one place, but never over a sufficiently wide area to make certain that the contact observed continues through the entire delta, or even most of the delta, at the same elevation. These elevations, which are shown graphically in Fig. 5, must therefore be considered as tentative determinations subject to possible revision if later it becomes apparent that any of the deltas are of compound structure, and were not built entirely with reference to a single water level.

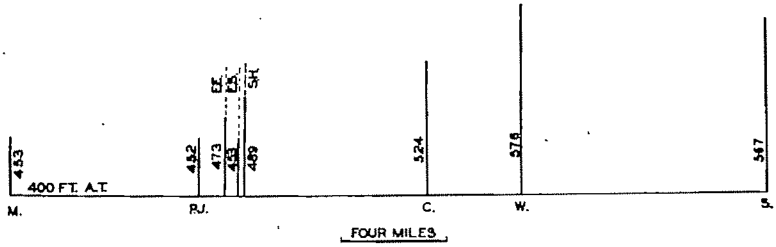

Fig. 5. Relative location of the deltas in Minisink Valley, and elevations of the topset-foreset contacts. M—Milford; PJ—Port Jervis; EE—delta at end of Martins Lake esker; ES—delta alongside Martins Lake esker; SH—Shin Hollow; C—Cuddebackville; W—Westbrookville; S—Summitville.

In general, the topset-foreset contacts, marking the water levels on the different deltas, occur at higher elevations as one proceeds northeastward. The explanation which naturally comes to mind, to account for such relations, is tilting of the land upward toward the north, since evidence of such tilting has been reported from the glaciated areas of New England, the St. Lawrence Valley and the Great Lakes region. Deformation of former horizontal shorelines by post-glacial tilting has also been described within 50 miles of the Minisink Valley, both in northeastern New Jersey[4] and in the Hudson Valley of eastern New York.[5]

There are, however, exceptions to the general northeastward rise, which seem to indicate that the Minisink Valley deltas do not record simply a former horizontal shoreline, later deformed by differential uptilting toward the north. In three of the deltas, at Milford, Port Jervis and alongside the Martins Lake esker, the topset-foreset contacts are essentially at the same elevation, 453 feet. Unless this coincidence of elevations is due solely to chance, it seems to indicate that these three deltas were originally built at the same level, and have not been affected by any important amount of later warping. It does not seem probable that the deltas were originally built at progressively lower elevations toward the north, and then raised to exactly the same level—so far as these three are concerned—by warping. Furthermore, the topset-foreset contact in the delta at the end of the esker, geographically between the deltas at Port Jervis and alongside the esker, is 20 feet higher than the contacts in these other two. This is most reasonably interpreted as indicating some difference in time of formation. The contact in the Shin Hollow delta is likewise 35 feet higher than that in the delta alongside the esker although these two are almost directly across the valley from each other. In this case the observed relations might be due either to difference in time of origin, or to accumulation in lakes at different levels but perhaps simultaneously in existence with an ice barrier between.

Difference in time of origin also seems a reasonable explanation of the fact that the topset-foreset contact in the Summitville delta is nine feet lower than that in the Westbrookville delta, although the former is eleven miles farther northeast. The difference in elevation here is so slight that it is quite possible the two deltas were originally built into the same lake and that relatively slight tilting has later displaced them a few feet. But such tilting would be contrary in direction to that which would be expected in view of the known history of other areas in northeastern North America which have been affected by post-glacial deformation. The significant fact, however, is that the relations of the water levels marked by these two deltas cannot be explained by simple, or even reasonably complicated, tilting of a former horizontal shoreline according to a theory of progressively greater uplift toward the north.

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[4] Salisbury, R. D., and Kummel, H. B.: "Lake Passaic, an Extinct Glacial Lake," Jour. Geol., Vol. 3, 533-560, 1895.

[5] Fairchild, H. L.: "Pleistocene Marine Submergence of the Hudson, Champlain and St. Lawrence Valleys," N. Y. State Mus. Bull. 209-210, 1919.

Finally, it seems improbable that the difference in elevation of the Cuddebackville and Westbrookville deltas is due entirely to deformation of a former horizontal shoreline, since this would require northward uptilting at an average rate of 15 feet per mile in the distance of three and a half miles between these two places.

As it does not seem possible to account for all of the deltas by deformation of a single, formerly horizontal shoreline, there must have been either a series of lakes in the valley, standing at different levels at the same time and presumably separated by glacial ice, or else a sequence of water levels at different times, in one or more lakes. There may, of course, have been both a series of contemporaneous lakes, and a sequence of different levels at which the water stood in these lakes.

CAUSE OF THE LACUSTRINE CONDITIONS.

There are four possible ways in which relatively quiet water, which must have been present when the deltas were formed, could have been held in the Minisink Valley at the levels indicated by the deltas:

1. A marine invasion due to regional subsidence of the land or eustatic rise of sea level, with warping of the shoreline to account for the present variation in elevations;
2. Tilting sufficient to reverse the present southward valley slope, while ice or glacial deposits blocked the northeastern end of the valley and prevented free drainage in that direction;
3. Ponding behind a recessional moraine, or several successive moraines;
4. Lakes along the valley sides, between the valley wall and ice occupying the median part of the valley, such ice being either a projecting tongue of live ice extending down the valley from an active glacial front, or stagnant ice left in the valley bottom during the last stages of melting.

Of these four possibilities, the first seems highly improbable because it would imply widespread and drastic disturbances in neighboring regions which could hardly have escaped recognition. No such extensive marine submergence seems to have occurred in the Delaware Valley since the last glaciation.

Reversal of the present slope of the valley bottom and ponding of the resulting northeastward drainage by glacial ice, or its deposits, seems possible so far as can be determined in the light of present knowledge. Between Milford and Westbrookville the tilting would have to be at an average rate of at least seven feet per mile, which seems rather high but not necessarily impossible. The coincidence in elevation of the Milford and Port Jervis deltas and the one alongside the esker is much more strongly suggestive of a sequence of lakes, with these three deltas formed in the same lake and unaffected by any considerable amount of later warping. A later warping may, however, have been markedly greater farther northeast and have been at least a contributory factor, even if not solely responsible for the formation of lakes in which the deltas were built.

A lake in the valley due to a moraine dam likewise must be considered possible. There is a conspicuous, although not large, moraine at Fisher School, about six miles southwest of the Milford delta, and some suggestion of the possible former existence of another moraine about half a mile south of Milford. Either of these might have served as a barrier to southward drainage and caused a lake, although there may be doubt whether either moraine could have been sufficiently massive to hold in a lake while the glacial ice, which built the moraine, was disappearing from the valley farther north to a sufficient extent to allow the accumulation of all the deltas. It is possible, however, that fluctuations in the level of such a lake might have caused the deltas to be built at two or more different elevations, and that some later warping may then have sufficed to produce the relations now observed between the different delta water levels.

Ponding of water between the valley walls and ice occupying the middle of the valley is also a plausible alternative explanation of conditions under which the deltas may have been formed. The existence of a series of such lateral lakes would be quite normal, it seems, if the last glacial ice became stagnant and melted in place by ablation, thus probably persisting longest in the deepest part of the valley while drainage was along the valley sides where it might easily be blocked by masses of ice or accumulations of debris banked against the valley sides. Such lateral lakes might also be formed along the sides of a projecting tongue of ice lying in the valley during retreat of a live ice front, especially at the mouths of tributaries where most of the deltas are located.

Any one of these three possibilities—(1) reversal of valley slope by tilting, (2) moraine damming, or (3) ponding of water between ice and the valley walls—seems adequate to account for the formation of lakes in which the deltas could have been built, but it may well be that the conditions which actually existed were due to a combination of any two, or all three, of these possibilities. It is not possible now to reach a final conclusion, but reversal of the valley slope seems least probable. A series of lateral lakes, alongside of either an ice tongue or persistent masses of stagnant ice, seems the most probable of the three possibilities, at least so far as the origin of most of the deltas is concerned. A moraine dammed lake is, however, at least equally probable in the case of the Milford delta, and this same lake may have extended northeast as far as the delta alongside the esker.

THE DISAPPEARANCE OF THE GLACIER ICE.

The disappearance of the glacier ice from the New Jersey part of the Minisink Valley has been described by Salisbury[6] in accord with what may be called the theory of marginal retreat. This theory postulates that the rate of melting at the glacial terminus became greater than the rate of forward movement of the ice, so that the glacial front retreated northward in the general direction from which the ice was at the same time flowing. In conformity with this interpretation, Salisbury described a recessional moraine at Fisher School, on the eastern side of the valley about a mile north of Dingmans Ferry. He also regarded two terraces on the eastern side of the valley, one at Montague just south of Milford and the other a short distance south of Port Jervis, as remnants of outwash plains built during later halts in the retreat of the ice (see Fig. 3).

This retreat theory has more recently been questioned by Cook[7] who, considering primarily evidence in the southeastern part of New York State including about half of the Minisink Valley, concluded that the glacier lost its forward motion and became stagnant while practically at its greatest extent, and then melted away dominantly by ablation, becoming separated into many isolated ice masses which remained in the valleys after the higher areas were exposed.

[6] Salisbury, Rollin D.: op. cit., pp. 285-288, 297-303.

[7] Cook, John H.: op. cit.

Aside from the problem of whether the glacier lost its forward motion as a general phenomenon due to some fundamental cause affecting wide areas and not determinable within the Minisink Valley region, the essential difference between these theories concerns the relative importance of the two melting processes, surface ablation and melting from the margin inward. Neither theory requires that only one of the two processes be effective. In the interpretation of the aqueoglacial deposits of the Minisink Valley, however, the divergent expectable effects according to the two different theories become important factors. The retreat theory implies that fluvioglacial outwash deposits would be spread across the valley bottom south of the Summitville divide, but as the ice retreated north from the divide a lake would be impounded between the divide and the retreating ice front until the latter had receded far enough to open a lower outlet by way of the Hudson Valley. While the lake existed, its outlet stream would flow southeastward across the divide and probably tend to trench the outwash plain previously built up in the valley southwest of the divide. If this condition prevailed terraces now found along the valley sides southwest of Summitville might be remnants of outwash plains which once extended across the entire width of the valley. But if stagnation took place, the bottom of the valley would be the last area occupied by ice and outwash deposits might be confined chiefly to the form of kame terraces along the valley sides both north and south of the divide, with temporary lakes probably existing both in kettle-like depressions in the deposits of the valley bottom and between the shrinking bodies of ice and the valley sides.

The available evidence does not seem to support either theory solely and to the exclusion of the other. Detailed study of the moraine and outwash plain at Fisher School, on the eastern side of the valley a mile north of Dingmans Ferry, leaves no doubt that a live ice front stood for some time at this position, more than thirty miles inside the recognized southern limit of the last glacial stage. The moraine forms a hummocky ridge which ascends diagonally up the eastern valley side from the school house, rising northeastward about 200 feet per mile after emerging from the outwash plain at an altitude of about 480 feet, or slightly more than 100 feet above the present river level. The moraine is clearly traceable to the crest of the first minor ridge east of the river, at an altitude of about 800 feet. The easternmost point at which it is clearly defined is about five miles northwest of the western end of what Salisbury[8] called the Ogdensburg-Culvers Gap recessional moraine on the eastern side of Kittatinny Mountain, and as there is much confused, moraine-like topography between, it seems quite probable that the two were contemporaneous in origin, as Salisbury suggested. The continuation of the Fisher School moraine has not been recognized west of the Delaware, but later fluvial erosion may have partly removed and partly obscured it within the valley, while on the bordering plateau upland there has been much irregular glacial deposition and the moraine may continue there although not yet recognized as a distinct unit. There is, however, a prominent terrace at the village of Dingmans Ferry which almost certainly represents the former outwash plain, thus showing the valley was filled by this outwash on both sides of the present course of the Delaware. Figure 6 illustrates the relations of these significant features.

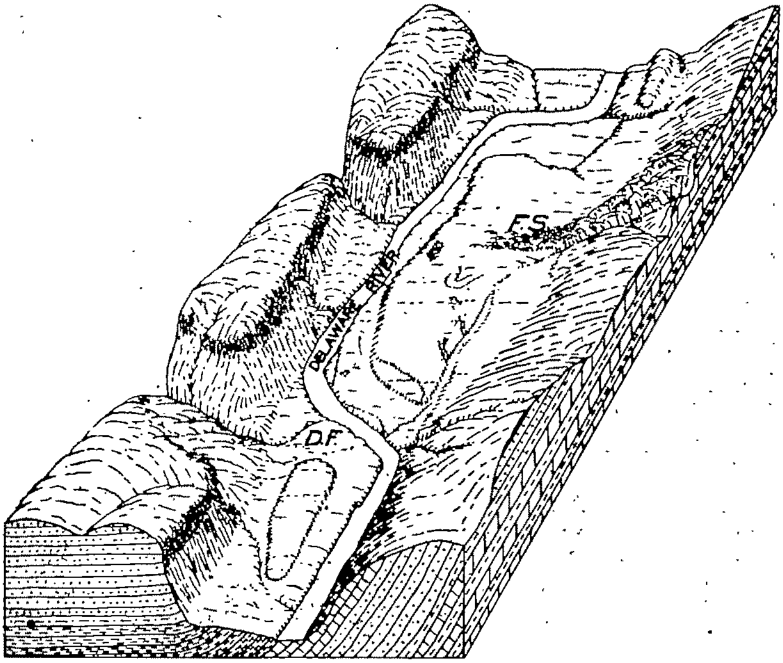

Fig. 6. Part of the Minisink Valley in the vicinity of Dingmans Ferry (D. F.), including the Fisher School moraine (F. S.).

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[8] Salisbury, Rollin D.: op. cit., pp. 350-355.

There are prominent high terraces on both sides of the valley at Montague, a mile downstream from Milford, which Salisbury[9] regarded as remnants of an outwash plain built during a second halt in the retreat of the ice front. The terrace on the eastern side of the river is covered with slope wash and fine wind blown sand which mask its original character. The terrace on the western side shows bouldery, kettle pitted topography which becomes smoother as the surface rises gently toward the western valley wall. Road cuts show that at least the upper ten feet is composed of stream laid gravel. The terrace is about a mile long, and at its northern end is separated from the Milford delta terrace only by the narrow valley of a small stream, the two terraces being essentially at the same elevation and probably formerly continuous with each other. These relations suggest that there was ice in contact with the terrace, and so disposed as to force drainage along the valley wall, after the delta had been built to virtually its present size. Whether this was a retreating glacial tongue or only stagnant ice persisting in the valley bottom and melting from the sides inward, is uncertain. There is an unusual amount of hummocky topography on the minor ridges between Montague and the western slope of Kittatinny Mountain, which Salisbury suggested might represent a moraine built while an ice front crossed the valley at the head of these terraces, but the moraine is not clearly defined and cannot be shown to be certainly associated with the terraces.

There is another high terrace on the eastern side of the valley, with its upstream end about a mile south of Port Jervis, which Salisbury[10] thought might represent an outwash plain built during a third halt in the retreat of the ice front. The surface of this terrace slopes down southwestward about ten feet per mile. This slope and a pronounced decrease in the average size of surface boulders show that the terrace was built by drainage in that direction. Many large kettles pit the surface and along the northern margin there is an area of about an acre where hummocky, boulder-strewn topography rises about 25 feet above the adjacent smooth terrace surface, showing that an ice margin of some sort existed at this place. There is, however, no proof that there ever was an outwash plain extending entirely across the valley at the elevation of this high terrace, for the only suggestion of a similar surface on the opposite side of the valley is a pitted, gravelly terrace about 40 feet lower, shown by two closed 440-foot contours about a mile south of Matamoras on the topographic map. There is no evidence of a moraine associated with the high terrace, and it may be simply a kame terrace built between the eastern valley wall and ice occupying the deeper central part of the valley bottom.

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[9] Salisbury, Rollin D.: op. cit., p. 302.

[10] Salisbury, Rollin D.: op. cit., pp. 287, 303.

From Port Jervis northeast to Summitville, a distance of 25 miles, there are no significant features to show whether the ice disappeared from that part of the valley by retreat or by stagnation and melting in place. About ten miles northeast of Port Jervis there is a strong suggestion of a morainal belt extending about five miles eastward from the eastern base of Shawangunk Mountain at Otisville, but this moraine-like topography cannot be traced westward across the mountain into the Minisink Valley. There are many kame terraces along the valley sides and these, like the delta terraces, are pitted with kettles recording the presence of many ice masses, probably stagnant and partly buried. There are also groups of kame hillocks, particularly prominent at Haven, which surely were formed in contact with essentially stagnant ice, for they are well stratified, and show no structural disturbance such as would be expected if they had been formed in or against moving ice. In contrast with these deposits suggestive of stagnation are a number of isolated, gravelly and relatively flat-topped low terraces rising above the general surface of the valley bottom but not banked against the valley sides as are the kame terraces. These look like remnants of outwash surfaces, but they are neither large enough nor sufficiently numerous to prove that the valley as a whole was ever completely filled to the height of their summits.

The present divide between the Delaware and Hudson drainage is about one mile south of Summitville, where the valley bottom is a swampy, nearly flat surface with no bedrock protruding through the drift. This surface extends northward beyond Summitville with little change in elevation and no pronounced break in slope, but narrowing along the western side of a large hill of drift which has already been mentioned in connection with the Summitville delta. At Phillipsport, opposite the northern end of this drift hill, the valley bottom bordering the northward-flowing stream narrows to only a few hundred feet, and the surface descends northward much more steeply for about a quarter of a mile before widening to a broad, lower valley bottom north of the drift hill. The lower surface north of the drift hill does not appear to be due to fluvial removal of a former northward extension of the higher surface, but rather to an originally lower depositional surface on the drift. About half a mile north of Phillipsport several small exposures show laminated clay silts of lacustrine origin, which may represent accumulation either in small lakes along the valley side, or in a lake occupying this lower part of the valley bottom and perhaps draining southward across the site of the present divide while ice blocked the northeastward outlet to the Hudson. Cook[11] has specifically cited conditions at Summitville (see Fig. 2) in support of the theory of stagnation. He concluded that a retreating ice front north of Summitville would have caused ponding and forced drainage southward across the divide, but he believed that there had been such southward drainage only "while large masses of stagnant ice lay both north and south of it (the divide)." It seems, however, that there may be another interpretation which is equally plausible.

Test borings[12] show about 100 feet of sand, clay and gravel fill in the narrowest part of the valley bottom, between Summitville and Phillipsport. There does not appear to be such uniformity or definite textural sequence as would indicate lacustrine origin, but some of the material is sufficiently coarse to suggest very strongly that it is not a lacustrine accumulation. The topographic relations seemingly require that the accumulation took place while there was an ice barrier across the valley at or north of Phillipsport, since the material would presumably otherwise have been spread more widely northward. Such an ice barrier might be either a retreating live ice front, or a large stagnant mass of ice, perhaps buried under ablation moraine and augmented by kame deposits along its sides, persisting in that part of the valley after practically all ice had disappeared for some distance south of Phillipsport.

With a barrier of ice at or north of Phillipsport, the material now filling the valley just south of that village could have been brought into place either by drainage forced southward across the site of the present divide, or much less probably by ponding of the northward flow of several small streams which enter the valley between the divide and Phillipsport; it does not seem possible that this amount of filling could be due chiefly to wash from the immediately adjacent valley sides, which appear little dissected by post-glacial erosion. There is a strong suggestion of former southward forced drainage since the scarp at the front of the Summitville delta terrace has a very regular base line, as though trimmed by a stream of sufficient size to swing in a curve of large radius and arc. This would necessarily be a southward flowing stream since there is no available source for any large stream flowing northward at this place.

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[11] Cook, John H.: op. cit.

[12] Berkey, Charles P.: "Explorations on the Phillipsport Site," Supplementary Memorandum No. 16, Water Supply Reconnaissance, Vol. 1, New York City Board of Water Supply, 1921-23. Unpublished; manuscript copy in the Columbia University Library.

Cook recognized the evidence of such southward drainage, but limited it to a period while there was still much stagnant ice in the valley farther south. The evidence of stagnant ice farther south seems confined to groups of kame hillocks with what appear to be depositional rather than erosional forms, and kettles in the terraces which indicate the melting out of buried ice which must have been essentially stagnant. The relations of these to the surface of the filling in the valley bottom is everywhere such as might be accounted for by some aggradation of the valley bottom by southward drainage after the stagnant ice had disappeared from these kettles and from around the kame hillocks. This interpretation implies that most of the valley south of Summitville was never completely filled much above the present highest stream terraces which have no kettles or hummocky areas typical of kame terraces. If the kettle-pitted surfaces and kame hillocks originated before drainage was forced southward across the Summitville divide, then there is apparently no evidence that stagnation was more than a local phenomenon in the valley south of Summitville. Such local stagnation might reasonably be expected along the margin of a retreating tongue of live glacial ice.

In summary, the size and position of the kame and delta terraces certainly indicate that the ice in the valley must have been quite thin and inadequate to fill the entire valley width, at the time of their formation. The kame terrace along the east side of the valley below Port Jervis, and the Summitville delta terrace, must have been formed by water issuing almost directly from the ice. All of the delta terraces, and the high kame terraces, show surface forms indicative of the presence of at least considerable bodies of ice at the time of their formation. The Fisher School moraine certainly indicates that a live ice front existed at that place, and there may have been similar live ice fronts at Milford and Port Jervis, as well as at Otisville just across the Shawangunk ridge from the Minisink Valley. Kame hillocks were accumulated in contact with ice near Haven, and their positions indicate that there has been no general valley excavation at this place, such as has occurred in front of the Fisher School moraine.

CONCLUSION.

Critical consideration of such lines of evidence suggests that the dominant factor in the accumulation of the delta and kame terraces was the persistence of a comparatively small and thin body of ice in the bottom of the Minisink Valley, after most of the valley sides and the surrounding uplands had been uncovered. There does not appear to be any positive evidence to show whether this ice in the valley bottom was an attenuated tongue of live ice, or whether it consisted of isolated and stagnant masses, perhaps largely buried under ablation moraine. Even if the glacier were melting away without having lost its forward motion as a whole, surface melting might have been sufficiently effective to expose the higher land in a thinning peripheral zone. This would probably leave much ice separated into isolated masses in the valleys of the plateau, where it might become stagnant after being cut off from further supply by uncovering of the high divides at the heads of the valleys. An active, although thinning, glacial stream might at the same time continue to flow through the Minisink Valley as its margin retreated northeastward toward the low Summitville divide. On the other hand, even if the glacier did become stagnant due to some cause of wide effect, it is quite possible that an active ice stream would continue to flow through the deep Minisink Valley for some time, fed from a great reservoir of ice in the Hudson Valley lowland as long as this ice was sufficiently thick to overflow across the Summitville divide.

The delta terraces themselves were accumulated quite rapidly, and in some cases at least by streams issuing directly from the glacial ice. The most plausible explanation is that they were built into water ponded along the valley sides by morainal accumulations and buried ice, but at least one of the deltas, at Milford, and possibly also the Port Jervis delta, may have been formed in a lake dammed by a recessional moraine and perhaps extending across the entire valley width.

ACKNOWLEDGMENTS.

This paper has been based on field and laboratory studies carried on intermittently for a period of nearly three years under the direction of Prof. Douglas Johnson, to whom the author is grateful for much encouragement, advice and assistance. The current results of the studies were frequently presented orally to the Seminar in Geomorphology conducted at Columbia University by Professor Johnson and Dr. Henry S. Sharp, and members of the Seminar will recognize here the debt due them for their pertinent criticisms and helpful suggestions.

Soil Conservation Service,
Washington, D. C.

RECENT FAULT SCARPS, ORGAN MOUNTAIN DISTRICT, NEW MEXICO.

PARRY REICHE.

ABSTRACT.

Faulting is shown to have occurred in geologically recent times adjacent to the eastern margin of the Organ Mountains of central-southern New Mexico.

In Dona Ana County, New Mexico, about 19 miles east-northeast of Las Cruces, there is geomorphic evidence of recent faulting. For a distance of nearly four miles, scarps of fault origin interrupt the long slopes of recent alluvial cones along the eastern base of the Organ Mountains.

The geology of the adjacent mountains has been worked out in detail by Dunham,[1] whose report of the remarkably well displayed magmatic stoping was responsible for the writer's visit, and hence for the observations here set down. For the location of the area discussed and of possibly related bedrock structures, reference should be made to Plate II of Dunham's work.

The accompanying sketch (Fig. 1) shows the approximate disposition and extent of the scarps, which follow a broken line of three segments. That at the northwest trends N45W; the short middle segment bears N65W; the southern segment is at N45W near its northern end, at N30W near its southern termination. Scarp heights ranging up to 100 feet are indicated by figures on the sketch. The scarps slope northeasterly at angles of 29 to 35 degrees to the horizontal; both old and new alluvial cones slope between four and five degrees; the interfan surfaces below the scarps have slopes of a degree or so, except near the southern end of the displacements, where the older alluvium appears below as well as above the scarp, at its proper slope.

The material forming the scarps and extending upslope behind them, is a boulder gravel, sufficiently old to have acquired a pronounced reddish-brown color and a shallow, rather fine-textured soil, developed between the boulders. In the runoff channels which cross this material, and in the individual and in the coalescing fans built below and against the scarps, the boulder gravels are clean and of light gray hue.

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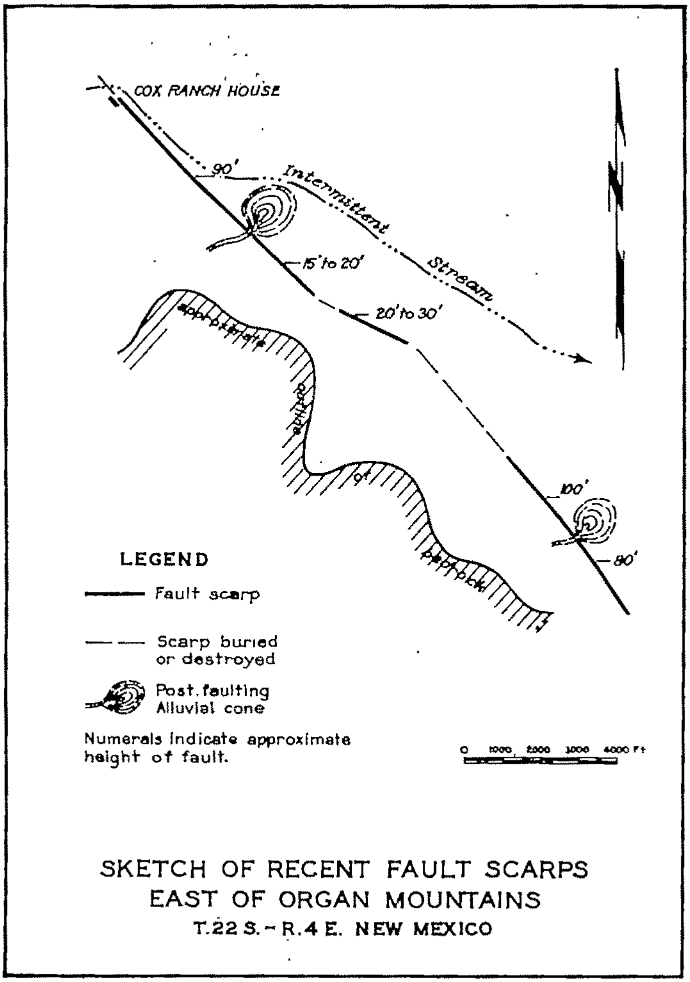
[1] Dunham, K. C.: Geology of the Organ Mountains. N. Mex. Sch. Mines, Bull. 11, 1935.



SKETCH OF RECENT FAULT SCARPS
EAST OF ORGAN MOUNTAINS
T.22 S. – R.4 E. NEW MEXICO

Fig. 1.

The color contrast between these pre- and post-faulting alluvia, derived from identical source rocks (chiefly monzonitic) is striking. It has been observed also at the only fault scarp previously reported from New Mexico, east of the northern end of the Magdalena Mountains, in Socorro County.[2] Unfortunately, the time required to produce marked surface oxidation and soil development under an arid climate is unknown. Below the scarps, between the post-faulting fans and coalesced fans, the nearly level surface is covered with the coarse sand fractions of the younger debris accumulations.

That the scarps were not formed by lateral cutting of the main drainage shown on the sketch, is evidenced by three circumstances: first, their pronounced linear character; second, the fact that, for such transverse cutting-off of nearly four miles of bouldery alluvial apron, all the many high-gradient watercourses in that stretch would have had to suspend delivery of debris, a manifest absurdity; third, the fact that near its southern termination the scarp visibly displaces the old oxidized bouldery fan.

While the gap between the southern and middle segments of the scarp-line is too wide to permit conclusion as to their relation, the junction of the northern and middle segments appears definitely and sharply angular. A faint expression of a northwest continuation of the middle segment may be traced almost to the mapped southern termination of the adjacent segment. The parallelism of the northern part of the southern segment and the entire northern segment furthers the suggestion that one is dealing here with an angular, broken-line pattern, rather than with a single sinuous displacement.

The initial throw of the faulting would appear to have been between 80 and 100 feet. In those places where the scarps are low or lacking it is evident that they have been destroyed, or have been partially buried by the deposition of boulder gravels and sands immediately below them. This is especially marked in the southern portion of the northern segment, where many ephemeral streams break across the scarp at close-spaced intervals. Of the two large post-faulting fans shown on the sketch, the northern has built up level with the scarp-top, the southern lacks about 12 feet of that height.

The stepped profile of two short gulches which cut across the northern part of the southern segment of the scarps, suggests that the displacement took place in three stages of, roughly, 30, 20 and 50 feet, successively. Possibly the local development of a fan, in the interval between the first and second of these postulated stages, is responsible for an offset in the older alluvium, near the south end of the scarps, of only about 40 feet, while less than a hundred yards to the northwest the scarp has a height of 80 feet. The actual direction of the movement, i.e., whether both sides or only one moved, and in the latter case, which, has not been determined. Certain of the data suggest, but inconclusively, that the absolute movement was a subsidence of the valley side.

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[2] Bryan, Kirk: Outline of the Geology and Groundwater Conditions of the Rio Grande Depression in Colorado and New Mexico. In Regional Planning Part 6. The Rio Grande Joint Investigation in the Upper Rio Grande Basin. National Resource Committee, p. 217, 1938. A reputed fault-scarp west of Tularosa was shown by Talmadge to result from wave action in a former lake. Talmadge, S. B.: Scarps in Tularosa Valley, N. M. Sci. n. s. v. 79, pp. 181-83, 1934.

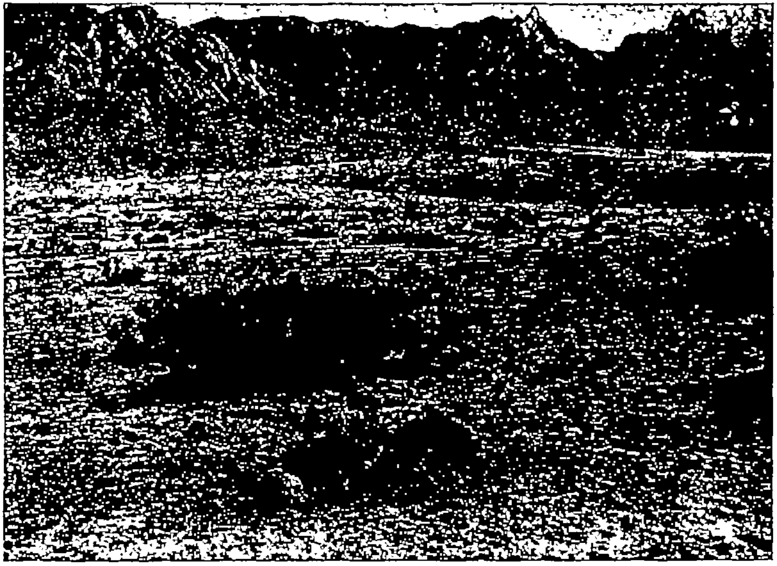

Fig. 2. Northern post-faulting fan and scarp segment, looking westerly.

A slight northeast-facing concavity of the scarp, between the ranch house and the larger post-faulting fan, may be noted. Along this stretch the main drainage from the northwest appears to have been diverted at the time of the displacement, so as to flow against the scarp-base. (See Fig. 2.) From that position it was rapidly forced by the development of the fan. Except in this northwestern stretch it appears unlikely that the scarps have receded appreciably since their formation; they have been destroyed by trenching and sidecutting in the gap between southern and middle segments, elsewhere aggradation below and against them has been more rapid than erosion, and has tended partially or completely to obliterate them.

It is not improbable that the faulting reported may be an extension of that shown by Dunham in the bedrock of the mountains, about a mile and a quarter south of San Augustin Pass.[3] It accords in direction with the group of post-mineralization faults which he distinguishes as including the latest disturbances of the district.[4] The dominant joint system of the adjacent salient of the mountains roughly parallels the trend of the scarps.

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[3] Dunham, K. C.: op. cit. Plate II.
[4] Idem, pp. 147-148.

ALBUQUERQUE, NEW MEXICO.

TWO CARBONIFEROUS INSECTS FROM THE VICINITY OF MAZON CREEK, ILLINOIS.

F. M. CARPENTER.

ABSTRACT.

Describes *Lithoneura lameerei*, new genus and species (Syntonopteridae, Palaeodictyoptera), the family Syntonopteridae being redefined; and *Adeloneura thompsoni*, new genus and species, of the new family Adeloneuridae (Protorthoptera). The affinities of the fossils are discussed in detail.

During the past few months the Museum of Comparative Zoölogy has been fortunate enough to receive two unusually good insects contained in ironstone nodules, from the vicinity of Mazon Creek. Since insects in any sort of preservation are exceedingly scarce in these nodules, and especially since the probability of securing additional specimens in the near future is very slight, I have decided to publish descriptions of the fossils at this time.

ORDER PALAEODICTYOPTERA.

Family Syntonopteridae Handlirsch.

This family is redefined here as follows:

Fore wing: archedictyon very feeble, numerous weak cross-veins present; intercalary veins present between the branches of Rs, MA, MP, and CuA; Rs arising close to base of the wing; MA, MP, CuA, and CuP present. *Hind wing*: similar to the fore wing in venation, but much broader basally, without an increase in the number of anal veins.

Prothoracic lobes are present, though small.

This family has previously included only the single species *Syntonoptera schucherti* Handl., from Mazon Creek.[1] It was necessarily characterized very broadly and loosely by Handlirsch, since he had only a fragment of one wing on which to base his diagnosis. His specimen did possess, however, one striking peculiarity: "longitudinal veins having the appearance of intercalary veins like those of the Plectoptera and Odonata." Handlirsch was under the impression that this was only "a superficial resemblance caused by their strongly S-shaped curve." In this conclusion, however, I believe Handlirsch was mistaken. An examination of the type of *S. schucherti* at the Yale Peabody Museum has convinced me that these are true intercalary veins. They invariably have the opposite position from the venational system in which they occur (i.e., the intercalary veins within the radial sector are convex, and those within the anterior media are concave, etc.); and they do not have distinct origins, but seem to arise from oblique cross-veins between the longitudinal veins.

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[1] This Journal, Vol. 37, p. 299, 1911.

The new fossil described below as *Lithoneura lameerei*, is the second Mazon Creek insect (and, so far as I am aware, likewise the second unquestionable Palaeodictyopteron) known to possess these intercalary veins; and since this specimen also has several other venational features in common with *Syntonoptera*, it seems advisable to place the two species together in the family Syntonopteridae, and to redefine that family as above, on the basis of the additional details furnished by the new specimen.

Genus Lithoneura, new genus.

Fore wing: costal area only moderately broad, with true cross-veins well developed; MA fused with Rs for a very short distance. *Hind wing*: similar to the fore in venation, the fusion of MA with Rs being more extensive; CuA coalesced with M basally, and 1A similarly fused with CuP.

This genus differs from *Syntonoptera* chiefly in having the basal coalescence of MA and Rs.

Genotype: *Lithoneura lameerei*, new species.

Lithoneura lameerei, new species.

Figs. 1 and 2.

Fore wing: length (as preserved), 32 mm.; width, 15 mm. Costal border arched basally; Sc approximately parallel to the anterior margin as far as preserved (middle of wing); R arched basally, but straight beyond; Rs gradually diverging from R near the very base of the wing, and coalesced with M for a short distance after its origin; R4 + 5 arising before the middle of the wing; R4 and R5 separating near to the posterior margin; M free at the base of the wing, dividing a little beyond the actual origin of Rs into MA and MP; after an abrupt anterior divergence MA fuses for a very short distance with Rs, and divides below the origin of R4 + 5; MP divides at a point much nearer its origin; CuA and CuP separate at the very base of the wing; CuA forked distally; CuP is unbranched; 4 anal veins apparently present.

Hind wing: length (as preserved), 27 mm.; width, 19 mm.

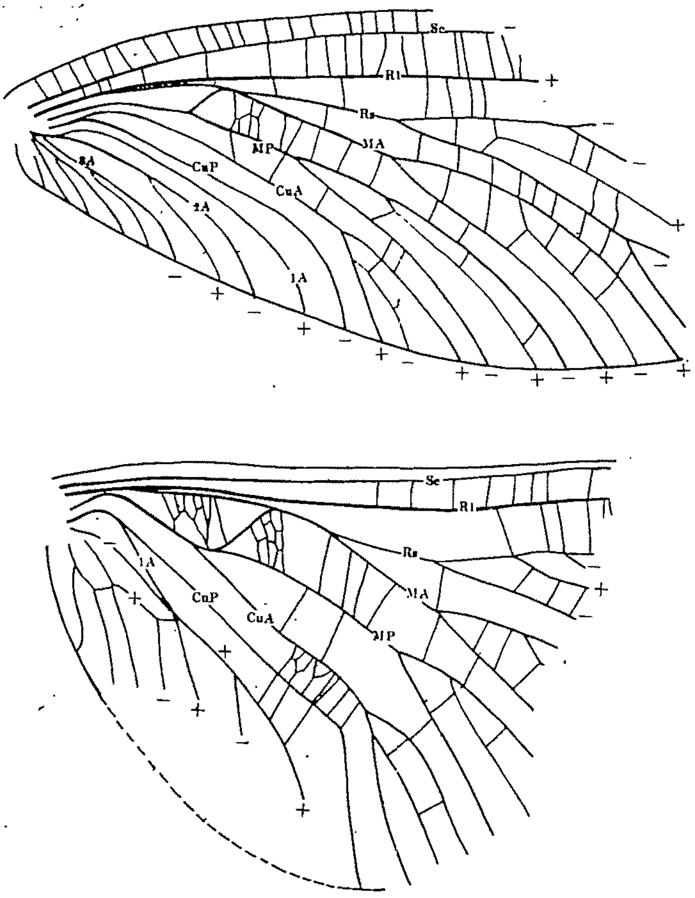

Fig. 1. *Lithoneura lameerei*, n. sp., drawn from holotype. Sc, subcosta; Rl, radius; Rs, radial sector; MA, anterior media; MP, posterior media; CuA, anterior cubitus; CuP, posterior cubitus; 1A, first anal vein. The convexity (+) or concavity (—) of the veins is indicated in the fore wing and anal area of the hind wing.

Costal margin very nearly straight; Sc close to margin; Rs arising close to base and branching as in the fore wing; M coalesced basally with CuA; M dividing into MA and MP almost immediately after its separation from CuA; MA diverges upwards and fuses with Rs as in fore wing, subsequently dividing below origin of R4 + 5; MP and CuA forked at about the same distance from the base of the wing; CuP coalesced basally with 1A, but soon separating, continuing straight for a considerable distance before finally diverging to the hind margin; 1A seems to give rise to two branches, both convex, with an intercalary vein between. Other veins in the anal area are highly modified and I am unable to homologize them.

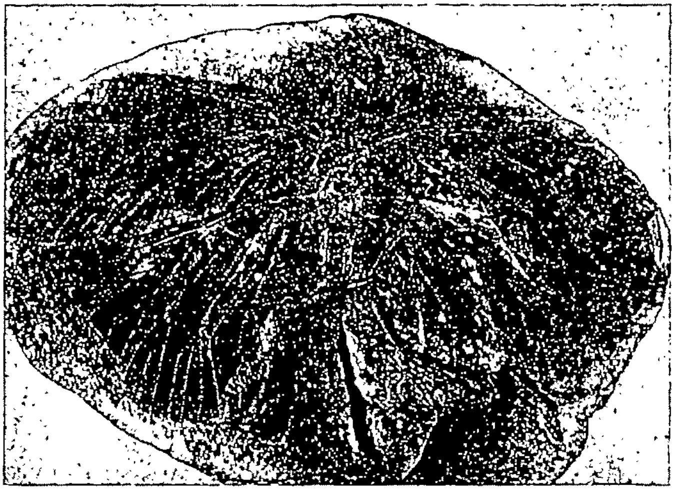

Fig. 2. *Lithoneura lameerei*, n. sp. Photograph of holotype. Wing expanse (as preserved), 62 mm.

Only faint traces of the body are preserved. The abdomen is slender, being about 2 mm. wide. Prothoracic lobes are clearly shown, and are 2.5 mm. wide and 4 mm. long (i.e., parallel with the longitudinal body axis).

Holotype: No. 4537, Museum of Comparative Zoölogy. The specimen collected at Braidwood, Illinois, and was included in the A. H. Conrad Collection, recently purchased from Ward's Natural Science Establishment. I believe it is one of the best Mazon Creek insects which has been found. It consists of most of the whole insect, the four wings being outstretched, with almost no overlapping; but since the body of the insect is at about the center of the small concretion, the distal half of each wing is missing. Details of the venation are unusually clear, especially in comparison with those of other insects from the same formation. As in the case of the type of *S. schu-*

cherti, the convexity and concavity of the veins are very strong. It is interesting to note that the venation of the left wings is almost identical with that of the right wings.

The species has been named for Prof. Aug. Lameere, of the University of Brussels, in recognition of his notable contributions to insect palaeontology and wing venation.

There are three features of this wing which are especially interesting:

(1). *The coalescence of MA and Rs.* This is the first instance of an unquestionable Palaeodictyopteron showing coalescence of these veins, though in most of the other orders of insects contemporaneous with the Palaeodictyoptera, such as the Protodonata, Megasecoptera, and some Protorthoptera, the coalescence of these veins had become well developed. The nature of the coalescence is particularly interesting in the hind wing; the area between M and Rs being much greater than in the fore wing, MA extends far out of its normal course in order to retain (or attain) the coalescence.

(2). *The differences between fore and hind wings.* Only a very few Palaeodictyoptera have been found showing even the bases of both fore and hind wings, and these are almost entirely members of more generalized families, such as Dictyoneuridae, in which the differences between the two pairs of wings are very slight. In the present Mazon Creek species the differences are very marked. Not only is the hind wing much broader than the fore, but it has a number of venational specializations not found in the other pair. The anterior cubitus (CuA), which is free in the fore wing, is coalesced with M in the hind pair, and 1A is apparently coalesced with the base of CuP. The remaining veins in the anal area of the hind wing are branched or joined to one another in a unique manner, but it should be noted that, regardless of the broader hind wing, the number of anal veins is not greater than in the fore wing.

(3). *The presence of intercalary veins.* These give a distinctly plectopterous appearance to the wings, a suggestion which is increased by other peculiarities of the venation. The brief coalescence of MA and Rs, for example, is very similar to that found in the Permian Plectoptera (as Protereismidae). In the hind wing there are also several other indications of Plectoptera, such as the strongly arched bases of M and Cu. Especially interesting is the contour of CuP, which, except for the lack of the curvature near the middle, is strikingly like that of the Permian Plectoptera (e.g., *Palingeniopsis* Martynov, Trav. Inst. Palaeozool. Acad. Sci. URSS, 1, p. 10, fig. 6, 1931). Even the specialized structure of the anal veins of the hind wing bears some suggestion of the anal veins of the Permian Protereismidae (e.g., *Protereisma* *permianum,* Till., Proc. Amer. Acad. Arts & Sci., 68 (11), fig. 20, 1933). I do not, however, consider these points of similarity sufficient to justify placing the Syntonopteridae within the order Plectoptera, chiefly for three reasons: (1) the archedictyon, which is present in the Syntonopteridae, even though faint, has not been found in any of the Plectoptera; (2) such specializations of the hind wing of the Syntonopteridae as the coalescence of CuA with M, and 1A with CuP are also unknown in the Plectoptera. (3) the fore and hind wings are widely different even in comparison with those of the Permian Plectoptera. In spite of these differences, however, it is very probable that the family Syntonopteridae occupied a position in the Palaeodictyoptera not far from the stock which produced the Plectoptera.

ORDER PROTORTHOPTERA.

Family Adeloneuridae, new family.

Fore (?) wing: costal space broad, traversed by several oblique veinlets; Rl unbranched, Rs with at least 3 branches (R2 + 3, R4, R5); MA absent; anterior branch of CuA coalesced basally with MP; CuP unbranched.

Genus Adeloneura, new genus.

Fore (?) wing: Rs arising slightly before the middle of the wing; MP separating from CuA slightly proximad of the origin of Rs, and dividing at about the middle of the wing into two main branches; CuA dividing basally into two main branches, the anterior one forked several times, the posterior one simple.

Genotype: *Adeloneura thompsoni,* new species.

Adeloneura thompsoni, new species.

Fig. 3.

Fore (?) wing: length, 35 mm.; width, 12 mm.; elongate-oval. Costal margin strongly curved, apex broadly rounded; Sc and Rl straight; Rs (in holotype) giving rise to an unbranched R2 + 3, and R4 and R5, the latter two veins being forked distally; each major branch of MP forked; CuA with at least 4 terminal branches.

Holotype: No. 4538, Museum of Comparative Zoölogy; collected at Wilmington, west of Coal City, Illinois, by Mr. John Herron and donated to the Museum by Mr. F. O. Thompson, for whom the species is named. The specimen consists of a fairly well preserved wing, with both obverse and reverse, complete except for the base of the costal area; it is contained in a moderately large concretion, about six inches long.

A second wing is preserved on the same concretion and is almost in contact with the former. These two wings, however, rest in opposite positions, i.e., the apices are together, and the bases remote from each other. In view of the fact that insects are extremely rare in the Mazon Creek nodules, it would seem at first glance that these wings were derived from a single specimen, having become detached from the body.[2] However, although the wings are identical in size and have essentially the same venation, they differ in so many details that I find it difficult to accept that explanation. There is the possibility, of course, that one of these wings is a fore wing and the other a hind wing, but there are hardly enough differences to support that conclusion. There can be no question, however, that these two wings belong to the same species, and in the absence of proof to the contrary, I prefer to regard them as fore wings

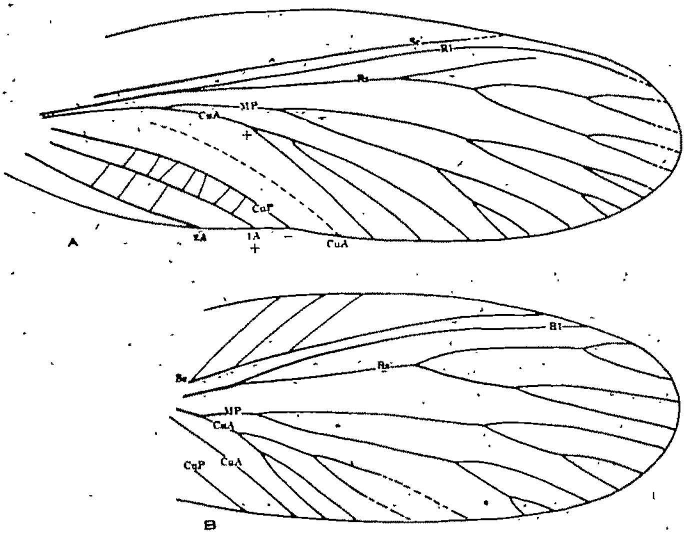

Fig. 3. *Adeloneura thompsoni*, n. sp. A, holotype; B, paratype. Lettering as in Fig. 1. The second branch of CuA (represented in A by a broken line) is not preserved in the holotype, but is present in the paratype.

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[2] So far as I am aware no other single concretion has been found containing two specimens of insects.

of different specimens. The second wing (Fig. 1B) is consequently designated as a paratype (No. 4539).

The two wings supplement each other in many respects, certain veins being better preserved in one specimen than the other. In the paratype, for example, there are distinct veinlets in the costal area, though these are not preserved in the holotype. In the paratype, also, there is a vein anterior to CuP, which I have considered to be a posterior branch of CuA. This is not preserved in the holotype, since most of that part of the wing is broken away. The main differences between the wings are in the branching of the main veins, and although these are more numerous than we would expect to find in the right and left wings of the same individual, they are not too great to occur in different specimens of the same species.

The affinities of this species are very uncertain. I have considered it necessary to establish a new family for it, since it does not fit into any that have been described. Unfortunately, many of the families which Handlirsch has established within the Protorthoptera[8] are based upon minute fragments of wings, too incomplete to show even specific characteristics. The only species known from the Mazon Creek nodules to which Adeloneura shows any affinities is *Cheliphlebia mazona* Handl., but the type is too small a fragment to provide a basis for comparison.

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[8] I include Handlirsch's Protoblattoidea within the Protorthoptera, since there seem to be no valid characteristics separating these groups.

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DISCUSSIONS AND COMMUNICATIONS.

DEVONIAN AMMONOIDS OF NORTH AMERICA AND THEIR MIGRATION ROUTES.

A monograph recently published by Dr. Arthur K. Miller[1] brings up interesting questions regarding the migration routes of the Devonian ammonoids on which the present writer wishes to comment. His remarks have been sent to Doctor Miller, and the latter's discussion of them is appended.

The monograph brings together all that is known of the twenty-two genera and seventy-five species of Devonian goniatites in this country. It is a detailed modernization of the old genera and species, most of which have been studied by Hall, Clarke, and Raymond, but which have otherwise received very little attention. The introductory matter has to do with distribution (pp. 1-12), terminology (12-15), phylogeny (15-19), and classification (19-25); the remainder is occupied by the systematic paleontology.

In America the ammonoids make their first appearance in two species in the Onondaga, the genera represented being *Agoniatites* and *Tornoceras*. The younger Marcellus also has these Middle Devonian genera, with the addition of single species of *Lobobactrites, Werneroceras,* and *Parodoceras*; and it is the first formation to have an abundant ammonoid fauna.

So far as is definitely known, nothing new is added until Genesee time, which shows the first typical assemblage of early Upper Devonian (Frasnian) goniatites, with *Bactrites, Probeloceras, Manticoceras* (8 forms), *Tornoceras,* and probably *Ponticeras* and *Koenenites*. In Indiana, the New Albany shale has *Werneroceras* and *Manticoceras*; the Antrim of Michigan, *Bactrites, Manticoceras,* and *Tornoceras*; the Lime Creek, *Manticoceras*; and in Alberta occur *Manticoceras, Tornoceras, Aulatornoceras,* and *Timanites.*

The Naples of New York has *Probeloceras, Manticoceras* (8 forms), *Neomanticoceras, Eobeloceras, Tornoceras, Aulatornoceras, Acanthoclymenia,* and probably *Schindewolfoceras*. "It is noteworthy that the first of the American beloceratoids, the first of the American prolecanitids, and the first of the clymenids appear in this assemblage" (p. 8).

In the Chemung of New York occur *Manticoceras* (6), *Tornoceras, Aulatornoceras,* and *Schindewolfoceras*. These, in general, are "rather closely related to those of the underlying Naples." With the exception of *Sporadoceras* of the Conewango, the still younger late Devonian ammonoid faunas of eastern North America introduce no new genera, all being "lingering elements of the Chemung fauna" (p. 9). However, in western United States *Raymondiceras* and *Pleuroclymenia* appear in the Three Forks shale.

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[1] Miller, Arthur K.: Devonian ammonoids of North America. Geol. Soc. America, Special Papers, No. 14, pp. 262, 39 pls., 41 text figs., 1938.

From the above it is clear that migrant goniatites were introduced into eastern North America three times, (1) in the Onondaga, (2) in the Marcellus, and (3), in greatest numbers, in the Genesee.

The following genera and species occur only in eastern (east of Michigan) North America: *Lobobactrites, Werneroceras* (2), *Probeloceras, Neomanticoceras, Eobeloceras, Parodoceras, Aulatornoceras, Sandbergeroceras, Schindewolfoceras* (2), *Sporadoceras,* and *Acanthoclymenia.* Occurring both east and west are *Bactrites* (6 in E., 2 in W.), *Agoniatites* (6 and 2), *Manticoceras* (23 and 6), *Tornoceras* (8 and 4). Restricted to west of Michigan are *Ponticeras, Koenenites, Timanites, Raymondiceras,* and *Pleuroclymenia* (2). As these figures show, the great majority of these forms occur in the east, and as most of the genera appear to be of European origin, the question must be asked, by what route did these faunas get into eastern North America?

In 1910, in his "Paleogeography of North America," the reviewer answered this question as follows: "Late in the Middle Devonic the Arctic waters again spread southward, introducing a Euro-Asiatic assemblage of life in the Cordilleran sea. At the close of this epoch this fauna spread through the Dakota sea and connected with the Mississippi basin across Michigan, thus distributing the *Hypothyris cuboides* [better, Tully] fauna into New York. Later in the Upper Devonic the *Spirifer hungerfordi* fauna is general from California to Iowa, and from Bisbee, Arizona, to Montana. To a limited degree it reaches the Mackenzie Basin, and late in Upper Devonic time [we would now say in Portage time] it extends to central New York. There is, however, another faunal element in the eastern region, best known in central New York, which, through many years of persistent collecting by Clarke, has grown to considerable proportions. This is the biota of the Portage [beginning in the Genesee] . . . In the entire western or Dakota sea there is nothing that can be directly compared with the Portage, while the goniatites and bivalves of the latter formation are in perfect agreement with those of western Germany. Not only has this fauna spread through the New Jersey straits, but also the *Spirifer disjunctus* fauna of the Chemung, both of which have decided Atlantic and European affinities."

The Genesee-Portage sea "deposited a black shale from New York to southwestern Illinois, but its waters did not communicate with the Gulf of Mexico" (p. 542).

On two or three occasions, when the reviewer stated these views before the Paleontological Society, his friend John M. Clarke arose to object to the entrance of these faunas through the "New Jersey straits," since he wanted to bring them from the northwest. It now appears that both these routes of migrations are impossible ones. However, as there are so many generic elements of western European and North Atlantic origin in the Upper Devonian of New York and the Appalachian geosyncline, the reviewer has for some years now been suggesting that the northeastern Atlantic seaway of migration appears to have come in across the province of Quebec north of the St. Lawrence River, entered New York west of the Adirondacks, and thence spread southeast into the Appalachian trough. CHARLES SCHUCHERT.

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NEW HAVEN, CONN.

Ammonoids are so much more abundant and varied in the European than in the American Devonian, that, with certain exceptions, it seems logical to regard our forms as migrants from the Eastern Hemisphere. Furthermore, each of our faunas has a close counterpart in Europe, where the sequence is more nearly complete and is better known. The relative scarcity of ammonoids in the Devonian of western America is to a certain extent more apparent than real, for no such intensive collecting as was done in New York has ever been carried out in the western portions of our continent. Also, the few specimens known from western America came from several widely separated localities, indicating that ammonoids in reality have a considerable extent there. Very little significance should be attributed to the fact that *Bactrites, Agoniatites, Manticoceras,* and *Tornoceras* occur in both the eastern and the western portions of North America, for all of these genera are ubiquitous. However, the apparent absence from the prolific faunas of eastern America of such widespread lower Upper Devonian forms as *Koenenites* and *Timanites,* and the restricted occurrence of *Probeloceras,* are probably very important from a paleogeographic point of view. Similarly, the late Devonian *Pleuroclymenia* and *Raymondiceras* do not occur in the Appalachian region. These facts seem to indicate separate invasions of eastern and western America. However, the northerly distribution of our Devonian faunas suggests that in each case the migration was from the far north across Canada into the United States. A. K. MILLER.

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SCIENTIFIC INTELLIGENCE.

PHYSICS.

Introduction to College Physics; by C. M. KILBY. Pp. ix, 398; 389 figs. Second edition. New York, 1938 (D. VanNostrand Co., $3.25).—This second edition resembles its predecessor, published in 1929, in brevity and simplicity. Not only is it one of the shortest college texts available, but its treatment of the subject is as direct as may well be found. The style is painstakingly simple and clear, and the author has evidently made some study of secondary school physics textbooks in planning his approach. In topical scope the book is similar to other college texts intended for the usual introductory liberal arts course. Time and space are, however, saved by avoiding formality and rigor, and by the omission of detailed description and explanation of applications and auxiliary phenomena. Photographic reproductions are few; the author states his preference for diagrams, of which there are many, as better pedagogical aids. The historical background is touched very lightly, being confined in the main to names and dates associated with important discoveries. The field of modern physics is limited to brief conventional accounts of gaseous discharge, X-rays, photoelectricity and radioactivity, with a short paragraph on cosmic rays. No very recent progress in these subjects is treated, except for occasional references to modern practical applications. A group of brief simple problems, chiefly numerical, follows each chapter. In the effort to simplify treatment of the subject the author, in the minds of many, will be considered to have gone too far, and the same criticism may be applied to a number of diagrams, which give the appearance occasionally of ambiguity or inaccuracy. A. T. WATERMAN.

The World of Atoms; by ARTHUR HAAS. Second edition enlarged and revised. Translated by GEORGE B. WELCH. Pp. xiv, 183; 52 figs. New York, 1937 (D. Van Nostrand Co., $3.00).—The sensational developments in the realm of atomic and nuclear physics since the appearance of the first edition of this book in 1927 have led the author to a revision and extension, which has been translated by Professor Welch with the aid of the translation of the earlier edition by Prof. Horace S. Uhler. The book, originally based on a series of popular lectures, is again intended to be read with interest by the layman; as such it is a welcome addition to the many expositions of physical topics from the pen of this author. A. T. WATERMAN.

An Outline of Physics; by ALBERT EDWARD CASWELL. Revised edition. Pp. ix, 590; 373 figs. New York, 1938 (The Macmillan Co., $3.75).—In planning this revision of his book published in 1928, the author has retained the same general form but the material has been extensively worked over and altered. It is designed chiefly for the majority of students in a beginning course in physics, namely those who do not plan further work in the subject. It is subdivided into six books, entitled *Properties of Matter, Mechanics, Heat, Electricity and Magnetism, Light and Sound,* and *Modern Physics,* so planned as to lend themselves readily to grouping by the three term method or the two semester. There are a number of novel features in the manner of presentation, which break with the traditional order in an interesting way. For example, in the introductory "book" the student is introduced in a preliminary fashion to many of the important physical concepts throughout the entire subject, such as energy, temperature, the electron, and atomic and molecular structure. The mechanics (statics) of fluids is treated chiefly in this first book where it is closely associated with the special properties of solids, elasticity and expansion, leaving most of the more formal parts of mechanics, except statics, to Book II. Electricity makes its entry *via* current electricity, the unit of electrical quantity being defined from electrolysis. Magnetism is not introduced until the electrical circuit and electrolysis have been disposed of, and is then closely associated with electricity. Incidentally the modern nomenclature has been adopted in magnetism. Sound follows light, wave motion having been discussed at the end of mechanics. The final section on modern physics is more detailed than found in most texts of this grade and is quite up to date. Numerous questions and problems are included, the answers to the odd-numbered of which are given at the back of the book. A. T. WATERMAN.

CHEMISTRY.

Elementary Principles of Qualitative Analysis; by T. R. HOGNESS and W. C. JOHNSON. Pp. x, 325; 27 figs., 37 tables. New York, 1938 (Henry Holt and Co.).—This book is really an abridgment of the larger text by the same authors, and is designed primarily for use in those schools which offer qualitative analysis, not as a course in itself, but as a part of the work in general chemistry.

As would be expected, the treatment in this smaller text follows closely the lines of its parent. Theoretical and practical chemistry are taken up in separate sections—to be studied concurrently—and we are glad to note that the theoretical section which we considered so excellent in the original text, has been but little curtailed. In fact, substantially two-thirds of the present text deals with the principles so necessary to an understanding of analytical separations. This section is particularly well supplied with exercises and problems which test the student's grasp of the subject material.

In the analytical part, the abridgment is most evident. Only nineteen metal and five non-metal ions are tested. The methods of detection are entirely orthodox, but with the omission of most of the ions which present any difficulty of separation, the analysis is greatly simplified, and will require far less laboratory time than the fuller courses.

Although the authors recommend the use of rather small samples for analysis, this is really to train the student in careful manipulation. The procedures use none of the "micro" or specialized tests for the detection of minute amounts of ions, and no special apparatus is required. E. B. KELSEY.

Qualitative Chemical Analysis; by LOUIS J. CURTMAN. Revised edition. Pp. xii, 514; 43 figs. New York, 1938 (The Macmillan Co., $3.75).—This text, although termed a revision of the author's earlier work, is really a thorough job of rewriting. The theory of solutions has undergone extensive changes during recent years, and many of these changes are here reflected in the rather extensive theoretical section with which the book opens. We notice in particular a chapter on the structure of compounds in terms of modern concepts, which leads logically through a discussion of the Coördination Theory into the Bronsted ideas of acids and bases. This seems to us the most logical and understandable development of these topics which we have yet encountered, and the author continues to use and apply these same ideas throughout the entire theoretical section. The discussions are well supported by adequate problems to illustrate the essential applications of equilibrium, solubility product, hydrolysis and the like, to analytical separations.

Changes in the cation analysis are less striking, although improved procedures have been introduced frequently. This section is noteworthy, however, for the real wealth of material included and for the copious annotation on the various procedures, which afford reasons for, and cautions in carrying out, nearly every step of the analytical work. We have really a good reference book instead of a mere text-book.

Anion analysis, too frequently neglected, receives equal status with the detection of cations. We are extremely pleased to find this so, for no other phase of analysis requires a greater variety of chemical knowledge or is of greater value in developing thoughtful work on the part of the student.

The author indicates that the text may be used either in full-year analytical courses, or (by omitting certain sections) in shorter, supplementary courses. We feel that it will not be so easy for the instructor to make such an abridgment, and that the text will find its greatest value in the full-time, professional courses, or as a reference text.

A rather short section is included which deals with the principles of micro-analysis, and discusses briefly some of the technique and procedures of this type of work. While this section is sound enough, it is hardly detailed enough to be of great value. But even neglecting this section completely, we have a thoroughly fine text which is an asset in the analytical field. E. B. KELSEY.

Chemistry of the Proteins. Second Edition; by DOROTHY JORDAN LLOYD and AGNES SHORE. Pp. xi, 532; 101 illustrations. Philadelphia, 1938 (P. Blakiston's Son and Co., $5.50).—It is with real enthusiasm that one can write a review of this excellent volume which can be recommended as the best available work on the subject of proteins. Coming as it does, twelve years after the first edition, it has had to be almost completely rewritten. The plan of the original volume has been retained, the subject matter being divided into two parts, the constitutional and the physical chemistry of the proteins. Under the former subject attention has been given to the latest theories of protein structure including a discussion of the cyclol theory. The physical chemistry of the proteins, in which enormous advances have taken place in the last decade, is also adequately handled with presentation among other things of the modern theory of titration of the ampholytes and the results of the X-ray study of proteins, including many X-ray diagrams.

In conclusion one can quote the last paragraph of the Introduction, written by Sir F. Gowland Hopkins, Nobel laureate, "I am so sure of the merits of Dr. Jordan Lloyd's work, that I take great pride in being allowed to write this foreword."

ROBERT D. COGHILL.

Actualités Scientifiques et Industrielles, Nos. 567 and 568, Philosophie et Histoires des Mesures; by M. GUICHARD. Essai Historiquès sur les Mesures en Chimie (a) Avant Lavoisier, (b) Avec Lavoisier, (c) Après Lavoisier. Paris (Hermann & Cie, Price 10 Fr. Each).—This essay is a short history of the development of exact measurement in chemistry. As the title indicates, Lavoisier, no doubt correctly, is given the lion's share of the credit for placing chemistry on an exact basis. It appears to the reviewer that the author is too critical of the theoretical speculations of the earlier chemists. Without doubt our present ideas will be regarded as childish by chemists of two hundred years hence. H. C. THOMAS.

Actualités Scientifiques et Industrielles, No. 566, Philosophie et Histoire des Mesures; No. I, De la Sensation à la Méthode de Mesure; par M. GUICHARD. Pp. 35. Paris (Hermann & Cie. Price 10 Fr.).—This essay deals with the human senses and their relation to scientific measurements. In the first portion of the essay the author discusses the various senses from the point of view of what information they can give us. The latter part of the essay is taken up with a discussion of how the natural senses have been replaced to a greater or less degree by more accurate methods of measurement. The author concludes that science might be built up entirely without the aid of the senses provided only that some "intellectual" method for detecting the position of a needle on a dial were afforded. H. C. THOMAS.

Actualités Scientifiques et Industrielles, No. 556, Recherches dans la Série de la Pyridine. Etudes de Quelques α-Pyridones; by M. J.-A. GAUTIER. Pp. 78. Paris (Hermann & Cie. Price 18 Fr.).—This work is a report of the preparation and study of several nitrogen substituted α-pyridones. The author has utilized the procedure of Decker for the synthesis from pyridine of the α-pyridones. After an introduction reviewing earlier work and discussing the theoretical questions involved in the study of N-substituted α-pyridones, the author proceeds to the description of the preparation, properties, and derivatives of N-β hydroxyethyl α-pyridone, N-β hydroxy-phenylethyl α-pyridone, N-(ethoxy-3-propanol-2) α-pyridone, N-(propyloxy-3-propanol-2) α-pyridone, N-(butyloxy-3-propanol-2) α-pyridone, and N-(isoamyloxy-3-propanol-2) α-pyridone. The molecular refractions of some of the α-pyridones are reported. A third part of the work treats the transformation by hydrogenation of some of the α-pyridones into piperidones. In a short appendix the physiological properties of some of the compounds is made the subject of discussion.

H. C. THOMAS.

Actualités Scientifiques et Industrielles, No. 529, Lecons de Chimie Physique Appliquée à la Biologie, J. Duclaux; No. X, Mouvement Brownien. I Partie Expérimentale. Pp. 89. Paris (Hermann & Cie. Price 25 Fr.).—The author starts with a historical survey of early work on Brownian movement. There is a long quotation from Smoluchowski's paper of 1906, which the author brings up to date by a discussion of later work. Next is given a critical résumé of the experimental evidence supporting the Einstein equation, as well as a description of the experimental methods used. The discussion is continued with a presentation of the evidence for the validity of Smoluchowski's equation for the distribution of small particles in a gravitational field. The author concludes that the determination of Avogadro's number from Brownian movement experiments can be considered accurate to only 5-10%. The closer agreement obtained is due to accident and a compensation of errors. The book is concluded with a short discussion of various special effects due to Brownian movement and with a discussion of Brownian movement in gases.

H. C. THOMAS.

GEOLOGY.

Lower Pliocene Mollusks and Echinoids from the Los Angeles Basin, California, and Their Inferred Environment; by W. P. WOODRING. U. S. Geol. Survey, Prof. Paper 190, pp. 1-58, plates 5-9, 1938.—Students of sedimentation and stratigraphy will be greatly interested in the analysis here made of the conditions of deposition of the chief oil-bearing formation of the Los Angeles Basin.

The study is based on material from the cores of 56 deep wells widely distributed over the basin. Among the 26 species of mollusks are several whose close relatives are now limited to deep water, while others are characteristic of shallow water and some to intermediate depths. The predominance of the deep water forms over the center of the basin and the limitation of the shallow water species to the northern border and western margin, lead to the conclusion that deposition of this Early Pliocene, Repetto, formation of the Los Angeles Basin had sea depths of 2000 to 4000 feet and was much like modern deep-water basins on the continental shelf of southern California. CARL O. DUNBAR.

Information préliminaires sur les Graptolithes du Tremadoc de la Pologne et sur leur portée theoretique; by ROMAN KOZLOWSKI. Ann. Mus. Zool. Polonici (Warsaw), Vol. 13, No. 16, pp. 183-196, 1938.—This extraordinary study is based on the most perfectly preserved graptolite material yet known. It is from beds of jasper in the upper Tremadoc horizon in Mount Ste. Croix south of Warsaw, Poland. When freed from the matrix by use of hydrofloric acid the graptolite remains are found to be of chitin but slightly altered, and to be readily bleached or sliced by a microtome. Among other phenomenal discoveries are a theca filled with eggs and another with embryos. Much information has been yielded on graptolite anatomy and biological relations.

No less remarkable than the state of preservation is the fact that the fauna is almost wholly undescribed and includes 3 new orders as well as 2 new families, 12 genera and 38 new species! All are benthonic and of the dendroid type. Equally striking is the presence among the graptolites of a hemichordate of the order Pterobranchia.

Professor Kozlowski has critically studied the evidence for kinship of the graptolites with other animals and concludes that they are not hydroids or bryozoans but are most closely related to the Pterobranchia among the Hemichordata, as Schepotieff suggested several years ago.

The complete monograph, now in press, on this material will be awaited with the greatest interest. CARL O. DUNBAR.

Species and Genera of Tertiary Noetinae; by F. STEARNS MACNEIL. U. S. Geol. Surv., Prof. Paper 189-A, pp. 1-39 and plates 1-6, 1938.—A complete taxonomic revision of an important subfamily of the pelecypod family Arcidae.

It is concluded that two groups of genera, one Atlantic and the other Pacific, have been largely independent in their development since Eocene time. Old species as well as new are effectively illustrated.
CARL O. DUNBAR.

BIOLOGY.

Evolution of the Annelida, Onychophora, and Arthropoda; by R. E. Snodgrass. Smithsonian Misc. Coll., Vol. 97, no. 6, pp. 1-159, 1938.—No brief review can do justice to this stimulating, philosophical study. It begins with consideration of the hypothetical annelid ancestor having the primitive simplicity of a gastrula, and traces the gradual modifications involved in the evolution of the three great groups under discussion.

Following three introductory chapters, the fourth is devoted to the adult annelid, the fifth to the *Onychophora* and the sixth to the *Arthropoda*. In each group the origin of the varied anatomical structures is accounted for. The final chapter is given over to a recapitulation of phylogenetic conclusions and ends with a phylogenetic tree.

The work is abundantly illustrated and includes an extensive bibliography. The unfortunate omission of any reference to P. E. Raymond's monograph on the Anatomy and Relationships of the Trilobites unfortunately leaves the non-specialist in this field wondering if other essential works have been overlooked.
CARL O. DUNBAR.

BOTANY.

Phytohormones; by F. W. WENT and KENNETH V. THIMANN. Pp. xi, 294; 62 figs. New York, 1937 (Macmillan Co., $4.00).—This volume is a most satisfying digest of the rapid developments that have occurred in the study of plant hormones. The subjects treated include the formation and occurrence of auxins, the relation of auxins to growth, their transport, chemistry, mechanism of the action and the part played by these substances in tropisms, root formation, bud inhibition and other activities of plants. An early chapter on the development of the hormone concept is particularly worthy of notice. A chapter on techniques for the determination of auxin is very helpful for the student entering this field as well as the many references included. The treatment is concise and succeeds in analyzing the problems of plant hormones and integrating the accumulated material in an excellent manner.
CARL G. DEUBER.

Agricultural Analysis a Handbook of Methods Excluding those for Soils; by C. HAROLD WRIGHT. Pp. ix, 343; 8 figs. London, 1938 (Thomas Murby & Co., 16s.).—This laboratory manual gives the details of the methods of analysis of fertilizers, feeding stuffs, milk, milk products, insecticides and fungicides. It is intended for agricultural chemists with limited library facilities. The author was formerly senior agricultural chemist in Nigeria. The clear style, helpful suggestions and evaluation of methods are commendable features of this work. CARL G. DEUBER.

Florida Wild Flowers; by MARY FRANCIS BAKER. Pp. xiii, 245; 47 plates. New York, 1938 (The Macmillan Co., $3.50).—Popularized descriptions of about eight hundred plants, with generalized keys based upon flower color and other obvious characteristics. G. E. NICHOLS.

Virginia Trees; by WILLIAM HARRISON LAMB. Vol. I. The Conifers. Pp. 112; 83 figs. Virginia, 1937 (Manassas Journal Press, $2.50).—A semi-popular account of the eight genera and twenty-one species of conifers native to Virginia, covering their taxonomic, ecological and economic features, together with a description of some thirty forest types found in that State.

G. E. NICHOLS.

Plant Ecology; by J. E. WEAVER and F. A. CLEMENTS. Second edition. Pp. xxii, 601; 272 figs. New York and London, 1938 (The McGraw-Hill Co., $5.00).—This book is a revision in the truest sense. As compared with the first edition, published in 1929, it bulks larger by eighty-three pages. This increase is due in part to the introduction of certain topics which were not included in the first edition—such, for example, as the method of pollen analysis, zonal soil groups, conservation of soil and water, and conservation of wild life; but in large measure the expansion is pretty well distributed throughout the book, the entire text having been gone over thoroughly with attention to both facts and presentation. Large parts of it have been completely rewritten, while advantageous changes in arrangement of material and in topical headings are evident throughout. The numerical increase in text figures (from 262 to 271) does not do justice to the improvement in this respect since, taking into account old figures omitted or replaced, the total number of new figures is more than 50. The bibliography has grown 606 to 1035 titles. Altogether the present volume is not only much more up-to-date; it is also much more readable than the original edition. G. E. NICHOLS.

Plant Physiology; by NICOLAI A. MAXIMOV, edited by R. B. HARVEY and A. E. MURNEEK. 2nd English ed. Pp. xxii, 473; 144 figs. New York and London, 1938 (McGraw-Hill Book Company, Price $4.50).—The earlier English edition of Dr. Maximov's textbook, published in 1930, was translated from the second Russian edition; the present volume is based upon the fifth.

This latter differs so radically from the first four editions as to practically constitute a new book. The subject matter has been completely rearranged in accordance with Maximov's growing conviction that the plant should be treated as "a unit organism in which all the parts and all the processes taking place in them are closely interrelated." The greater part of the text has been thoroughly rewritten, with the introduction of much recent material. There is little question that this modernized English version of Maximov's work, like its predecessor, will meet wide acceptance among American universities and colleges, especially those in which stress is placed upon the agricultural applications of plant physiology.

G. E. NICHOLS.

OBITUARY NOTES.

PROF. JOHN ORR HAMILTON, for twenty-nine years head of the department of physics in the Kansas State College of Agriculture and Applied Science, died on August 9 in his seventy-first year.

SIR ROBERT MOND, F.R.S., known for his researches in pure, applied and electrochemistry, and for his archaeological investigations in Egypt, Palestine and elsewhere, died on October 22, aged seventy-one.

PROF. JOHN E. OSTRANDER, "Johnny O" to thousands of students who passed through his classes during the thirty-seven years he taught mathematics at Massachusetts State College, died on October 19 at the age of seventy-three. Professor Ostrander, who retired from active teaching in 1935, attained wide recognition as a mathematician and astronomer.

DR. RAEMER REX RENSHAW died on September 23 at the age of fifty-eight. He had been senior professor of organic chemistry at New York University since 1924.

DR. ALLEN ROGERS, chemical engineer and supervisor of the department of chemical engineering at Pratt Institute, Brooklyn, since 1920, died on November 4 at the age of sixty-two.

DR. JOSEF ROSENTHAL, formerly of Munich, died at Hampstead, on August 7 last. As a young physicist, Rosenthal was one of the first to recognize the importance of Röntgen's discovery to medicine, and he devoted his life to the development of the X-ray tube, with special regard to its medical use.

DR. ALBERT SHERMAN, research associate and Stephen S. Wilder fellow of the Basic Science Research Laboratory at the University of Cincinnati, died suddenly on July 1 at the age of thirty-one. He had the opportunity of giving advanced courses in quantum mechanics, valence and thermodynamics, directing research and coöperating with the industries around Cincinnati. At the Symposium on Recent Advances in Chemical Physics of the American Association for the Advancement of Science, Dr. Sherman gave a paper on the "Calculation of Activation Energies," and in a forthcoming book he has contributed a chapter on the "Theoretical Basis of Hologenation Reactions."

PUBLICATIONS RECENTLY RECEIVED.

Annual Report of the Board of Regents of the Smithsonian Institution for the year 1937. Pp. xv, 580; 134 plates. Price $1.00 (paper cover).

Smithsonian Miscellaneous Collections. Vol. 97. No. 6. Evolution of the Annelida, Onychophora, and Arthropoda; by R. E. Snodgrass. Pp. 159: 54 figs.

The Sun Its Phenomena and Physical Features; by Giorgia Abetti. Translated by Alexandre Zimmerman and Frans Borghouts. New York and London, 1938 (D. Van Nostrand Co., $5.00).

An Introduction to Vertebrate Anatomy; by H. M. Messer. Pp. xvi, 406; 374 figs., New York, 1938 (The Macmillan Co., $3.50).

U. S. National Museum. Bulletin 170. Life Histories of North American Birds of Prey. Pt. 2. Orders Falconiformes and Strigiformes; by A. C. Bent. Pp. viii, 482; 92 plates. Price 60 cents.

Chemistry of the Proteins; by D. J. Lloyd and Agnes Shore. Second edition. Philadelphia, 1938 (P. Blakiston's Son & Co., $5.50).

Pharmaceutical Botany; by H. W. Youngken. Sixth edition. Pp. xxviii, 793; 507 figs., Philadelphia, 1938 (P. Blakiston's Son & Co., $4.75). A thoroughly modern textbook with pharmaceutical and medical applications, especially adapted for students of pharmacy and economic botany and as a reference for pharmacists, chemists, and students in structural and systematic botany.

The Cuban Operculate Land Shells of the Subfamily Chondropominae; by C. de la Torre and Paul Bartsch. No. 3039. From the Proceedings of the United States National Museum. Vol. 85, pp. 193-423; figs. 71-101, pls. 7-39. Washington, D. C., 1938.

Quelques Techniques Actuelles en Physique Nucléaire; par Jean Thibaud et al. Pp. vi, 276; 154 figs., 12 plates. Paris, 1938 (Gauthier-Villars, 100 fr.).

Année Polaire Internationale, 1932-33, Participation Francaise. Tome II: Electricité Atmosphérique; Courants Telluriques; Actinométrie; Radio-Electricité, Historique des Missions. Pp. 259; 117 figs., tables. Paris, 1938 (Gauthier-Villars).

International Encyclopedia of Unified Science. Volumes I and II: Foundations of the Unity of Science. Volume I. Number 5. Procedures of Empirical Science; by V. F. Lenzen. Pp. vii, 59. Chicago 1938 (The University of Chicago Press, $1.00).

The Perception of Light. An analysis of Visual Phenomena in Relation to Technical Problems of Vision and Illumination; by W. D. Wright. London and Glasgow, 1938 (Blackie & Son, 6s).

University of Washington Publications in Biology, Vol. 6, No. 1. Hepaticae of North America; by T. C. Frye and Lois Clark, Seattle, Washington, 1937 (University of Washington Press).

Patterns of Survival. An Anatomy of Life; by J. H. Bradley. New York, 1938 (The Macmillan Co., $2.25).

Illinois State Geological Survey. Publications on the Geology, Mineral Resources, and Mineral Industries of Illinois. With Appended Index. Pp. 112. Urbana, 1938.

Wissenschaftliche Ergebnisse. Der Niederländischen Expeditionen in Den Karakorum, und die Angrenzenden Gebiete in den Jahren, 1922, 1925, 1929-30 und 1935; von Dr. Ph. C. Visser und J. Visser-Hooft. Band II. Leiden, 1938 (E. J. Brill, 12 guilders).

Das Gletscherbuch. Rätsel und Romantik, Gestalt und Gesetz der Alpengletscher; von Walther Flaig. Leipzig, 1938 (F. A. Brockhaus, Geheftet RM. 7.50, Ganzleinen RM. 8.80).

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